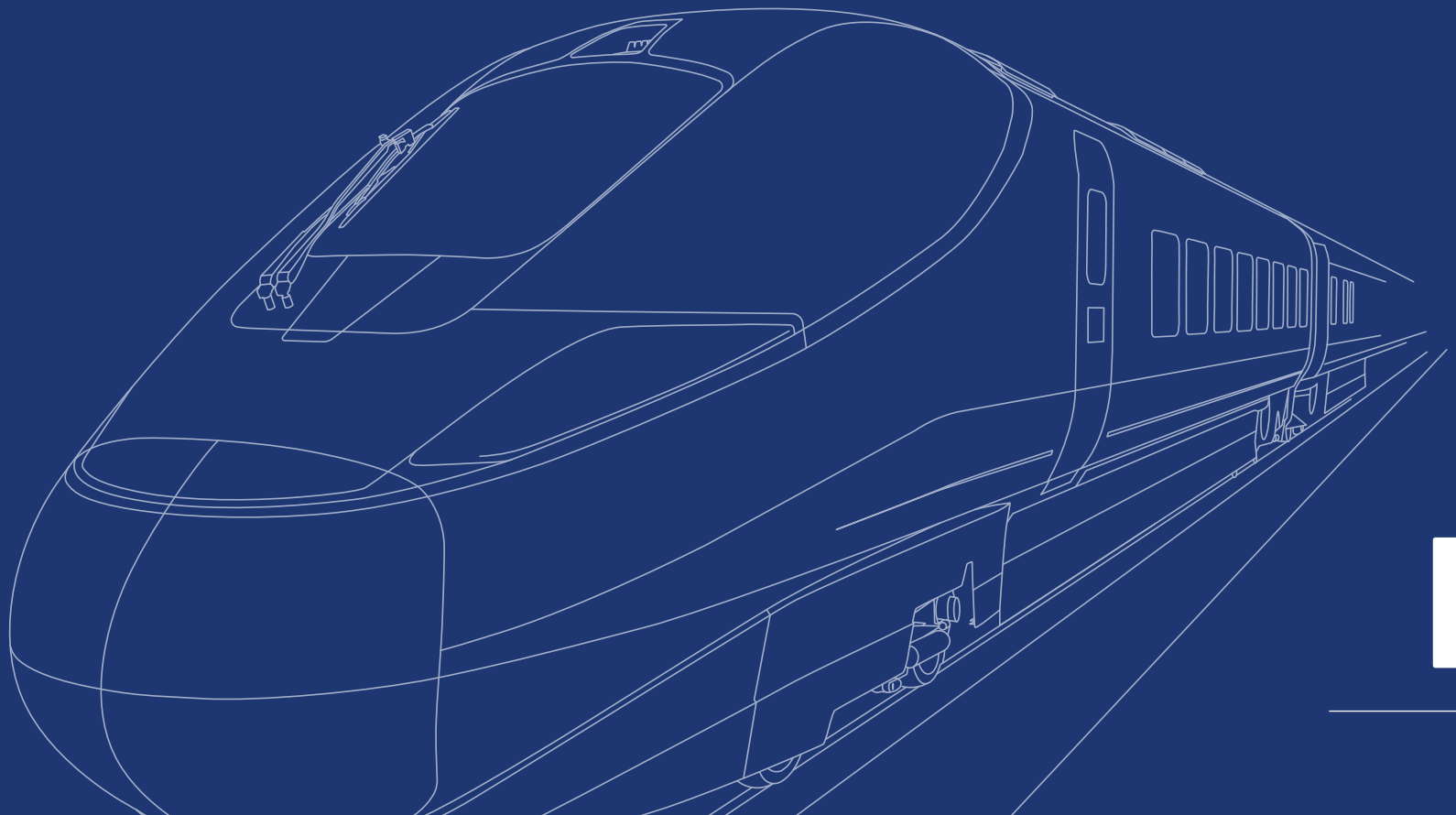
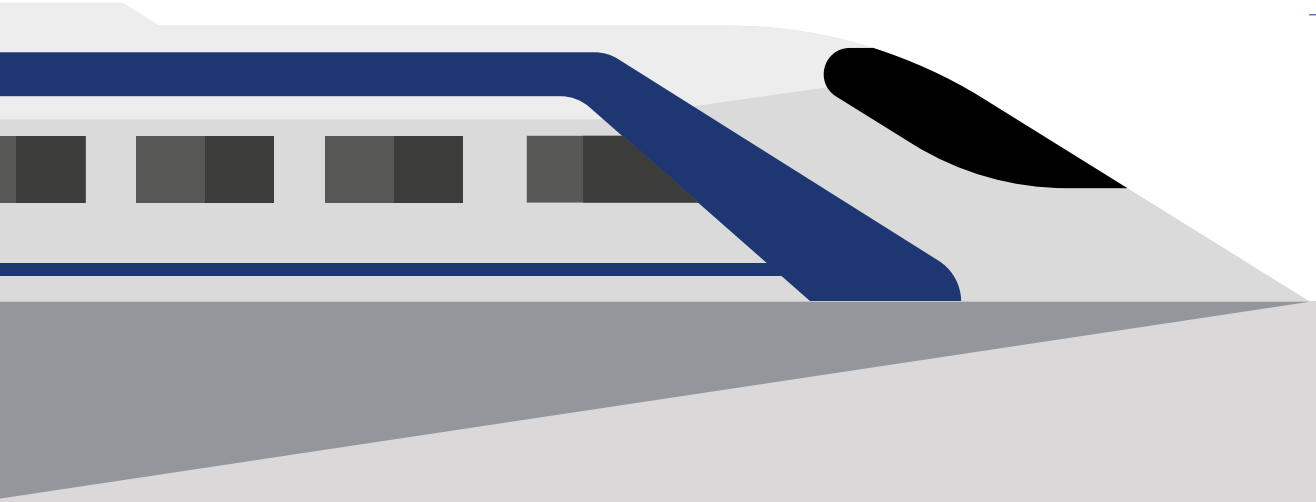
The Digital Twin
A vision for HS2



HS2

Contents



Foreword

HS2 is rightly recognised as a transformative infrastructure programme. It is a once-in-a-generation investment that will continue to deliver economic, social, and environmental benefits for the next 100 years.

The scale of transformation represented by HS2 can be compared to the expansion of the railway network in Victorian times. The new ability to travel at speed and in large numbers across the country changed working lives, led to the expansion of towns and cities, and fuelled economic growth by enabling the transport of goods and services between ports and people. The Victorian railways also enabled a range of other innovations, including the standardisation of time across the country (so that timetables could be established for reliable and safe train journeys), and the creation of the very first travel agency, Thomas Cook, born from the need to organise travel for large groups of people.

While delivering many similar modern-day economic, social, and environmental benefits is fundamental to our business case, HS2 also has a broader responsibility. As we are delivering the largest capital project in Europe, we have a responsibility to lead transformation in our industry and ensure that we use the very best approaches. That is why we are committed to building a "digital twin" of HS2, so that we can test and simulate every aspect of the railway in advance, from infrastructure and rolling stock to maintenance and passenger services. Using our Digital Twin, we will be able to do this at every stage of development from concept through commissioning, manufacturing, and onwards into operation.

We have produced this **Digital Twin Vision** document to help all of us understand not just the why and the what, but how we can all play our part in realising the benefits of the HS2 Digital Twin. Together we will move the HS2 Digital Twin from being the sole domain of our technology experts out into our wider, everyday activities.

Our investment in a digital twin is one of the ways in which we can truly say that HS2 is transforming our country, following in the footsteps of Victorian innovators like Stephenson and Brunel. That is an ambition worth striving for. We look forward to developing our Digital Twin together and unleashing not just its anticipated value, but also enabling benefits we haven't yet dreamed of.

Emma Head
Technical Services Delivery Director, HS2

Chris Rayner
Director of Stations & Systems, HS2

Executive summary

HS2 Ltd is delivering the largest infrastructure project in Europe. The organisation is large and complex, supported by a workforce of more than 25,000 people and over 2,000 suppliers.

Our objectives are clear:

- **Increase capacity for high-speed, low-carbon travel between the UK's major cities**
- **Increase opportunities for UK growth**

HS2 is a complex, highly-connected network. Its reliable delivery and operation will rely on many new high-tech systems and components not only working together as a new railway system, but also with an existing network that in places is over 100 years old. Whichever way you look at it, this is a highly complex and risky undertaking.

How can we minimise this risk by testing and practicing everything – every activity, every train, every scenario, every passenger journey, every event – for a one-off railway asset in complete realistic detail... virtually?

By developing and implementing existing technology to deliver an approach known as the "digital twin".

Digital twins are not brand-new technology. In fact, they have been used extensively by other sectors for more than 20 years. However, they are new in the infrastructure and railway operations sector, and that means strong leadership is required to benefit from their use. By taking a bold, necessary leadership position, HS2 can add another chapter to railway's impact on the development of not only technological, but social, economic, and environmental change across the UK.

Vision

A digital twin is a realistic digital version of a physical asset or network. Its processes and systems can closely represent the behaviours and movements of the physical built or natural environment, making it a reliable basis for decisions that are vital to a project or business.

The **HS2 Digital Twin** will hold requirements, designs, as-built and as-operated information, and – with the addition of sensors, behaviours, and machine learning – will be able to create a dynamic model that can mimic, simulate, and predict how HS2's assets and network will perform in real life, as illustrated below.

HS2 Digital Twin ambition

It is our ambition to be running the railway — and any critical processes — virtually at least two years before we do so physically.

The Digital Twin will not replicate or replace the many systems that we have invested in to date across HS2. Instead, it will provide cross-business data integrity and the ability to integrate insights from across the business, which will improve data quality.

This high-quality integrated data will power the Digital Twin's analytic, presentation and visualisation capability. The HS2 Digital Twin will also connect into a wider network of Digital Twins, e.g. contributing to the National Digital Twin agenda.

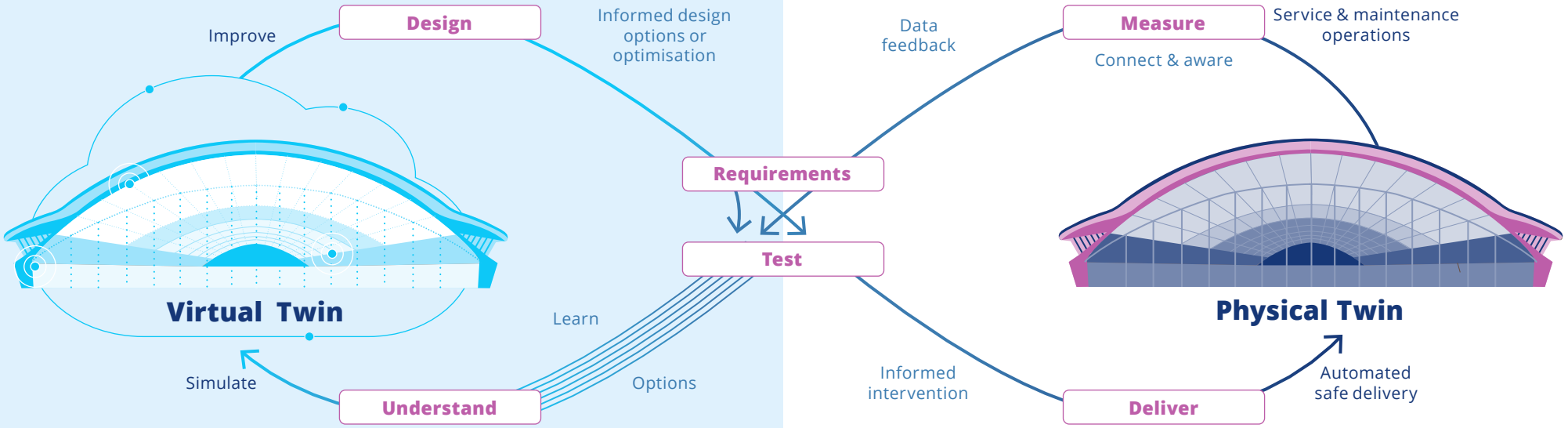


Figure 1. The HS2 Digital Twin, formed by progressively connecting existing activities and processes with an infinite, continuous improvement and learning loop.

Summary of objectives

What are the practical benefits and outcomes of the Digital Twin?

Reducing risk

The Digital Twin integrates and manages massive amounts of data: requirements, survey, design, commissioning, as-built, and sensor/telemetry. This allows specialist systems to operate autonomously while also providing data to the Digital Twin – it also makes it possible for us to create a complete, virtual representation of the HS2 network, its assets and rolling stock at any time in the past, present, or future.

Using complex algorithms and artificial intelligence, scenarios can be modelled to provide in-depth insights into how safety, operational, and interface activities and behaviours will play out in reality, ultimately reducing whole-life cost.

Increasing productivity

Building Information Modelling (BIM) has already shown how we can use data and information in new ways to improve design understanding, enabling benefits such as offsite manufacturing and lean approaches.

The Digital Twin will bring all of this capability to light, combining BIM and many other data types into massive, diverse data sets to drive real-life simulations. This will dramatically improve scenario planning and enable a full view of the overall productivity approach, including logistics, staff on-boarding, interface management, automation, and commissioning. Commissioning will be a particular focus of the Digital Twin, as it has proven to be the crux of many challenges experienced by comparable projects. It is our ambition to be running the HS2 railway and any critical processes virtually at least two years before we do so physically. These improvements in productivity will also extend to the reliability of service, e.g. reducing work during traffic hours.

Scenario planning

COVID-19 has demonstrated just how disruptive unexpected events can be, and continues to demand adaptation and innovation. As we learn to manage this unprecedented scenario, the Digital Twin will be able to develop predictive algorithms to plan mitigation, cleaning, segregation, and a host of other critical activities to ensure the network is up and running as quickly as possible, and start to rebuild the travelling public's trust.

Improving customer services

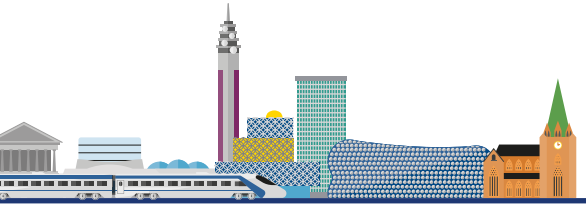
The Digital Twin will be used not only for delivery and operational issues, but also for services and service outcomes. These include improving interfaces with other operational rail and mobility networks, improving and optimising services to the travelling public, e.g. live customer feedback, and reducing consumer cost and carbon production.

Wider UK PLC benefits

The UK has long been at the vanguard of engineering and technological development. Capitalising on the opportunity of digital and digital twins will enable us to build a global leadership position.

There are also significant opportunities for growth in the technology sector. Market commentators indicate the potential for more than 520,000 new jobs over the next 20 years of HS2, many of which will be technology-related. This impressive job growth will extend beyond HS2, as significant numbers of high-quality technology employment opportunities will be created across the nation as a result of HS2's pioneering success and innovation. Rail systems and tunnelling training facilities could also be augmented by northern universities, some of which have a worldwide reputation for digital engineering, further supporting the UK's "levelling up" agenda.

Figure 2 illustrates the range of potential benefits.



Available infrastructure

Aware and alert assets proactively managing a high-quality service

- Resilient
- Predictive
- Wireless signals
- Robotics
- Self-healing
- Preventative
- Sensing

Operational response and disaster recovery

- Incident planning
- Response management
- Whole life decision support
- Scenario analysis
- Cyber security
- Optimised strategy, finance & investment planning

Autonomous maintenance and repair

- Automated service requests
- Internet of Things (IoT) monitoring
- Digital inspection and interpretation
- Optimised works delivery
- Engineering advisory and reliability action

Safety

- Passengers
- Maintenance crews
- Operating staff
- Members of public

Owners and operators

Open, transparent relations with operators and staff

- Train Operating Company (West Coast Partnership Ltd)
- Shareholders
- Unions
- Multi-mode
- Digital staff enablement

Stakeholders

Keeping our people and stakeholders connected and safe

HS2 High Speed 2
DfT Department for Transport
ORR Office of Rail & Road
TfL Transport for London
HMT HM Treasury
LEP Local Enterprise Partnerships
RAIB Rail Accident Investigation Branch
RSSB Rail Safety and Standards Board
Local Government particularly Mayors of London, Birmingham, Manchester, Leeds, and Sheffield)

Rolling stock

- Aware
- Experience
- Attractive
- Predictive
- Secure

Manufacturing

- Rolling stock
- Signals
- Design for Manufacture and Assembly civil assets

Delivery supply chain

Contractors & Utilities providing high-quality, green services we need

- Design
- Supply chain simulation
- Measurement
- DfMA
- Robotics
- Test & commission
- Logistics

Multi-modal concerns (at stations)

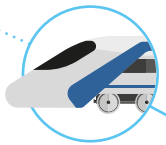
- Walking
- Buses
- Metro/Underground
- Cycling
- Light rail
- Taxis

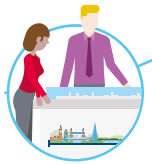
Customer / passenger

- Green miles
- Cost & value
- Connectivity
- Aware & informed
- Mobility as a service
- Predictable performance
- Experience

Energy

- Clean
- Reliable
- Green
- Optimised





HS2 Digital Twin

Figure 2. Illustrating the range of stakeholders and benefits supported by the Digital Twin.

How will the Digital Twin be delivered?

Implementing a digital twin at HS2 will be an enormous endeavour, but one with significant benefits potential.

We propose to de-risk the Programme by making the journey in a series of manageable steps, rather than one giant leap. By designing the implementation of the Digital Twin using a sequence of carefully defined Digital Twin "Horizons", we can learn as we go and carry over benefits and lessons learned from each step to the next.

The diagram shows each of three Digital Twin Horizons and their respective outcomes. All three horizons are built up using a combination of Technology, Process, Information and Organisational Capabilities.

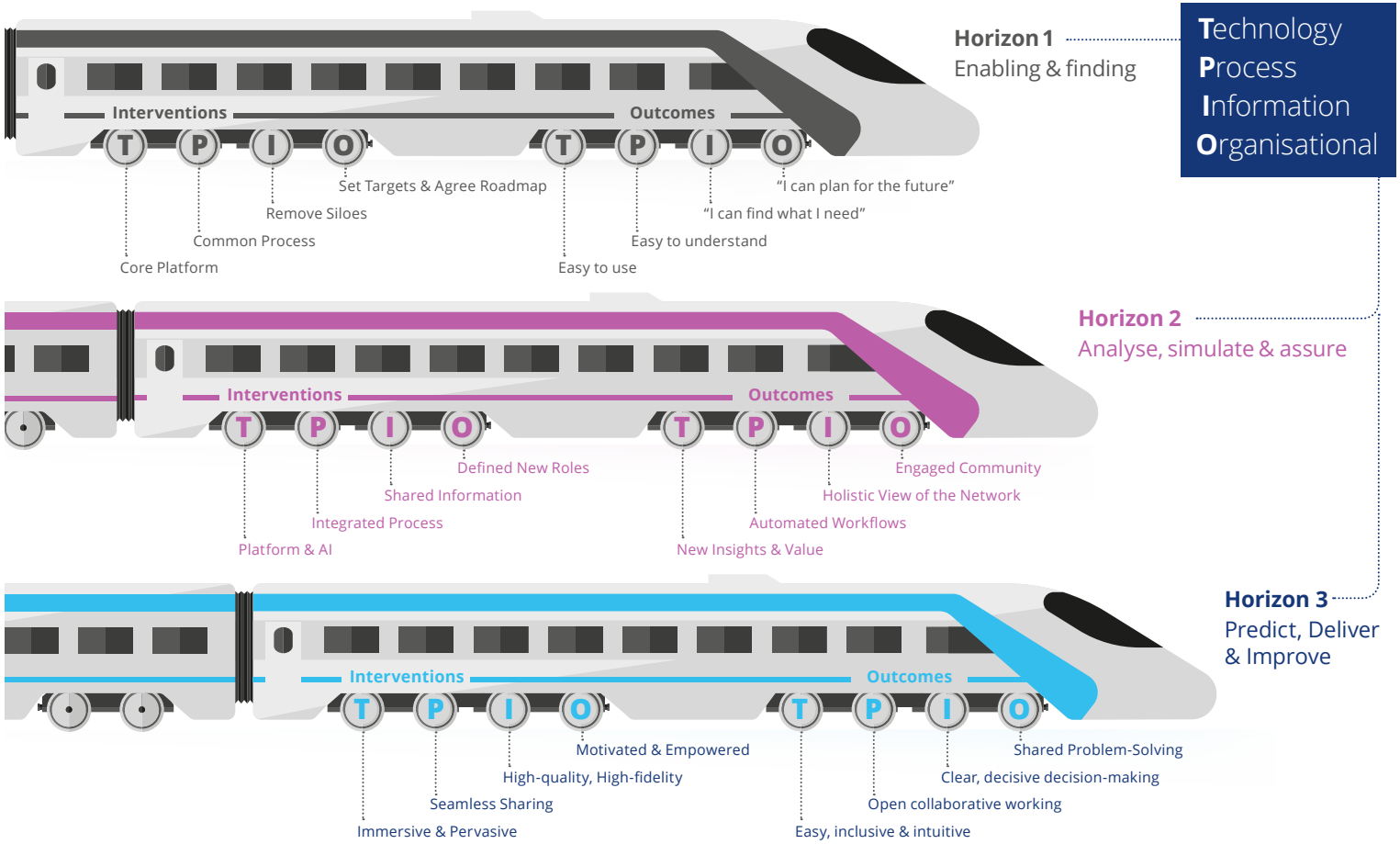


Figure 3. Digital Twin horizons and outcomes.

Who will use the HS2 Digital Twin?

The HS2 Digital Twin will deliver benefits to a wide range of users, from individual engineers within HS2 all the way to the travelling public and the communities it connects.

Figure 4 illustrates the idea that this benefit can be realised at many different scales and in many different contexts. For example:

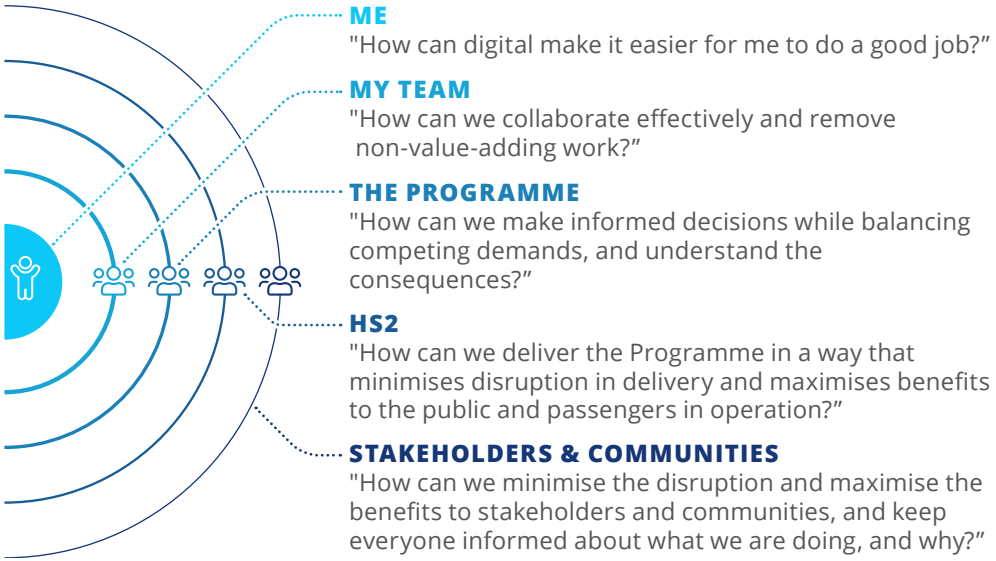


Figure 4. A schematic view of the spheres of influence of the Digital Twin, from individuals to communities.

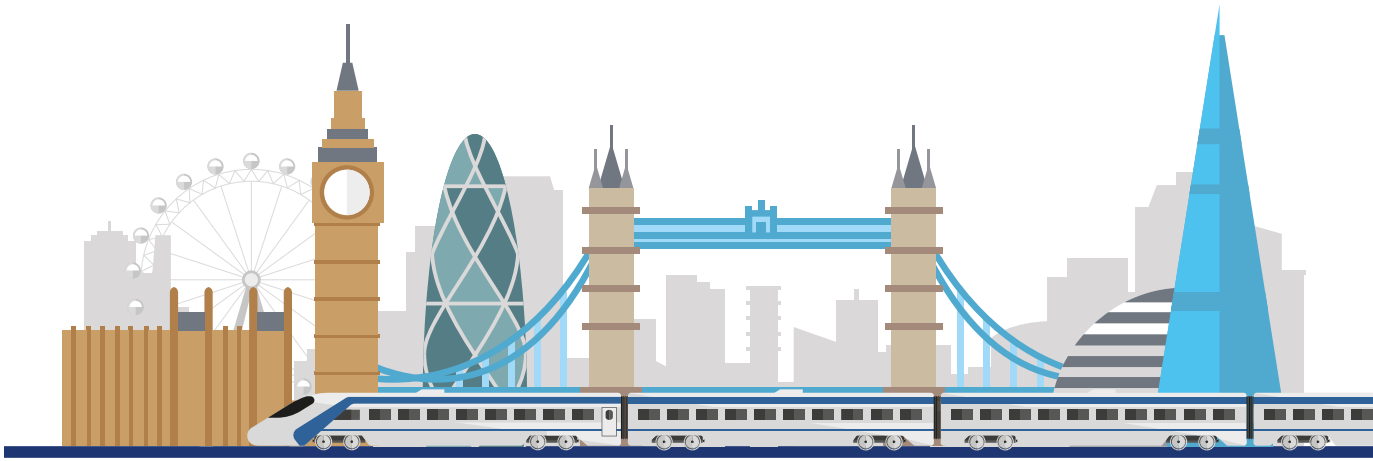
An individual engineer working in a team delivering part of the new infrastructure needs to be confident that their new track junction fits with the sections adjacent to it, both physically and functionally. This is so they can be assured that all of the requirements have been met, and that they have captured and shared all the information that will be needed by later teams to test, commission, operate, maintain, and use the railway.

The delivery team that the individual engineer is part of needs to be assured that the whole section of track meets requirements, so they will need to be able to compare information at different stages and answer key questions. Does the design meet the brief? Does the proposed construction meet the specification? What choices or selections have been made? Are there any unintended consequences from these choices?

The construction of the new railway has a direct physical impact on many communities. The team managing communications with these communities needs to have the best information about these impacts in advance, in order to manage and mitigate disruption. A Digital Twin that enables the visualisation of planned construction activities, alongside other scheduled events (e.g. school holidays, public holidays, adjacent work on the highways) will provide a richer insight into both risks and potential solutions.

HS2 is often described by people in the delivery team as a "system of systems". Assuring the successful integration of components within a single system has challenges – when integrating systems with other systems, this complexity is compounded. Taking a Digital Twin approach from the outset will enable the identification and progressive testing of dependencies between systems, using reliable data.

The HS2 Digital Twin will be a **realistic digital version** of the actual HS2 network, assets, rolling stock, and their interfaces. It will allow **complex integrated scenario testing** to simulate how the railway network will perform and behave at any point in time during the design, construction, commissioning, and operations phases. These tests and simulations will be able to evaluate possible scenarios in real-time and also in "time-lapse" mode.



Summary business case

The use of a Digital Twin on HS2 will create an eco-system that provides early, predictive awareness of network delivery, operations, and service outcomes. This will de-risk key elements of the Programme, prevent us from repeating mistakes made on similar projects, and provide a UK-wide platform for technology and high-value jobs, which can then be sold on a national and international stage.

Strategic case

HS2 aims to provide high-quality connectivity services between the north and south of the UK, to stimulate the economy in the north and to showcase top-quality UK technology and engineering. The main business plan has already made the case for the physical railway, but this Vision document is designed to present the strategic importance of maintaining a "virtual railway", the Digital Twin.

As the largest single project in Europe, HS2 is attracting worldwide interest. This distinctive project represents significant technological achievements and aims to deliver a high-profile, world-class tool set to reduce risk, improve safety, and drive business outcomes to success.

Reducing risk

With the ability to manage massive amounts of data in a digital ecosystem, it will be possible for us to create a holistic virtual representation of the network, its assets, and rolling stock at any time in the past, present, or future, i.e throughout the whole lifetime of operation and maintenance and eventually through to decommissioning. In this digital ecosystem, specialist systems will continue to operate autonomously but will provide requirements, survey, design, commissioning, as-built, and sensor/telemetry data to the Digital Twin. High-powered algorithms and artificial intelligence will enable us to model predictive and behavioural scenarios, providing in-depth insights as to how safety, operational, and interface activities and behaviours will play out in reality.

Increasing productivity

Building Information Modelling (BIM) has already shown how we can use data and information in new ways to improve design understanding, enabling benefits such as offsite manufacturing and Lean approaches.

The Digital Twin will bring all of this capability to light, pulling together BIM and many other data types into massive, diverse data sets to drive real-life simulations. This will dramatically improve scenario planning and enable a holistic view of the overall productivity approach, including logistics, interface management, automation, and commissioning. Commissioning will be a particular focus of the Digital Twin, as it has proven to be the crux of many challenges experienced by comparable projects. It is our ambition to be running the HS2 railway and any critical processes virtually at least two years before we do so physically.

Improving public services

The Digital Twin will be used to focus on services and service outcomes, in addition to delivery and operational issues. These include improving interfaces to other operational rail and mobility networks, improving and optimising services to the travelling public, and reducing consumer cost and carbon footprint.

Scenario planning

COVID-19 has demonstrated just how disruptive unexpected events can be, and continues to demand adaptation and innovation. As we learn to manage this unprecedented scenario, HS2 will be able to develop predictive algorithms to plan mitigation, cleaning, segregation, and a host of other critical activities to get the network up and running as soon as possible, and start to rebuild the traveling public's trust.

Wider UK PLC benefits

The UK has long been at the vanguard of engineering and technological development. Capitalising on the opportunity of digital and digital twins will enable us to build a global leadership position.

There is also significant technology sector growth opportunity. Market commentators indicate the potential for more than 520,000 new jobs over the next 20 years of HS2, many of which will be technology-related. This impressive job growth will extend beyond HS2, as significant numbers of high-quality technology employment opportunities will be created across the nation as a result of HS2's pioneering success and innovation. Rail systems and tunnelling training facilities could also be augmented by northern universities such as the University of Salford, which has a worldwide reputation for digital engineering, further supporting the UK's "levelling up" agenda.

Economic case

Due to the holistic scope of a Digital Twin, the economic case only really has three option scenarios:

The Reference case is to do nothing. This option fails to fulfil the fundamental purpose of the Digital Twin and will force HS2 to fall back on traditional methods which, as similar projects have demonstrated, will fail to equip the business with the necessary capability to deliver on its objectives. This option also fails to deliver the potential technology sector growth and job opportunities.

The Preferred case is to develop and deliver a digital twin for the entire HS2 network, associated assets, and rolling stock on a whole-life basis. This will deliver all of the benefits identified in this Vision document, including Delivery Phase efficiencies, commissioning, systems integration, and wider UK PLC jobs and growth opportunities.

The final option is to focus the Preferred case in a smaller geographic region, potentially focusing on high-risk areas. This option would provide some risk management benefits, but would fail to deliver the end-to-end systems integrity simulation, the full systems integration, or the simulation potential. Additionally, if the option fails to work properly, it will jeopardize the UK PLC benefits through low credibility.

Having considered the options, HS2 has recommended the Preferred case based on the risk and benefit profile.

The following Critical Success Factors have been identified to calibrate and benchmark the project:

1. **Scalability –** The Digital Twin must be able to reliably manage and process large volumes of data from large geographical areas of the network. This data must be high quality. It must be able to scale "vertically" to cover an increasing volume of various data types, and scale "horizontally" to cover many asset types and types of geography. The Digital Twin must also be scalable over time so that future requirements can be accommodated.
2. **Ability to predict future conditions reliably –** It isn't enough to just replicate the functions of Geographic Information Systems (GIS) and BIM. The Digital Twin has to provide further useful, reliable insights into the network and its assets and their future performance.
3. **Support a reliable benefits case –** The cost of the service must derive a significant return on investment and the Programme needs to demonstrate increasing benefit at each delivery Horizon.
4. **End-to-end capability –** The eco system must understand the end-to-end process across the entire network and the scope of its services.
5. **Create sector growth and job opportunities –** The approach must demonstrate technology sector growth and provide a platform for a multitude of high-skilled jobs in the UK.

Commercial case

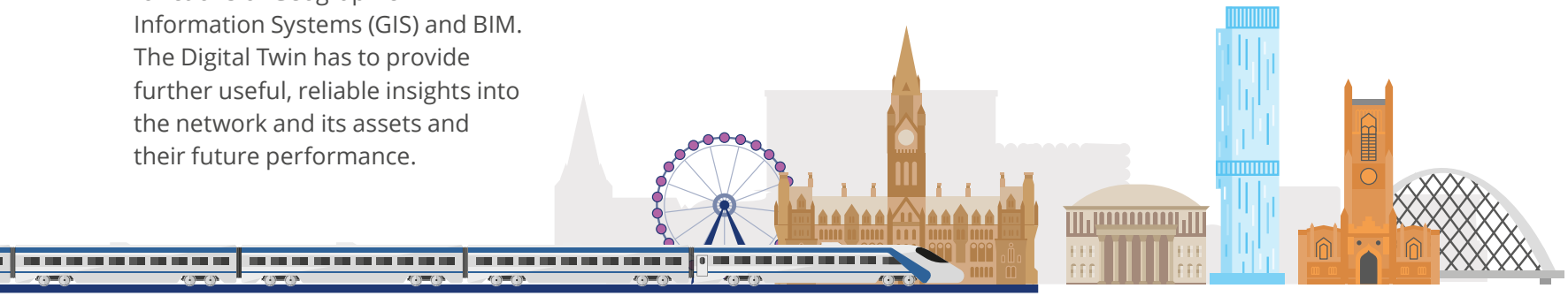
The scope of this Vision document only allows for a high-level articulation of the costs, benefits, and options appraisal. We will be taking feedback from this document and selected a Delivery Partner during 2021.

The Digital Twin project will be delivered over several Horizons. Approvals for subsequent Horizons will depend on the Programme achieving the Critical Success Factors (described above) in earlier Horizons. We will set up an Integrated Project Team (IPT) supported by a governance structure and steering board to establish the skills and capabilities needed to address the various facets of the project.

Management case

The Digital Twin project will be delivered by an IPT made up of resources from all HS2 departments, Digital Twin Delivery Partner and the specialist supply chain. The IPT will be responsible for the delivery of the project, the realisation of benefits, and full project participation by stakeholders both inside and outside the immediate HS2 community.

The IPT will also be responsible for ensuring that the solution is configured to be compatible with working requirements in a post-COVID-19 world.



Appendix A – case studies

This Digital Twin Vision sets out our ambition. To deliver it we will need to continue to develop and deliver our Digital Twin programme, working progressively to deliver capabilities in line with the three Horizons described in this Vision.

In doing so we will take advantage of lessons learned in other industries where Digital Twin capabilities are more advanced. This appendix provides some relevant examples.

Ports Digital Twin Case Study

Client profile

Client is a shipping port with over 4 million tonnes of cargo passing through each year, more than 400 employees and £50m + of yearly revenue.

Client challenge

Develop a Simulation Digital Twin to answer key questions about the identified use cases based on proof of value and feasibility: port and yard management, vessel berthing optimisation and demand and resource optimisation.

Solution approach

The Simulation Digital Twin was developed as a data-driven solution and according to the client SME's knowledge. It was designed to cover what-if scenarios such as: new equipment acquisition, cranes breakdowns and the testing of an optimised berthing schedule.

Outcomes / lessons learnt

- The Simulation Digital Twin helped to understand all of the processes inside the system.
- The what-if scenarios answered the key questions about the identified use cases.
- The Digital Twin could be used for measuring the impact of an external solution: an optimised berthing schedule, which helped the client to see its benefits.

Oil and Gas Digital Twin Case Study

Client profile

Client is the largest Oil and Gas company in Japan with business in both upstream and downstream of the Oil and Gas Value chain, more than USD 9 billion in revenue and more than 40,000 employees.

Client challenge

- The client was facing challenges due to having multiple departments, all of which were working in silos using their own systems, e.g. SAP PM for maintenance, OSI Pi for operation, Meridium for Asset Performance. There was no single source of truth.
- There were no central, asset-centric relationships, which often leads to higher maintenance and inspection cost.
- Final Product cost was high due to the higher operation and maintenance cost involved.
- Quick turnaround was the major challenge which the organisation wants to overcome.

Solution approach

The complete project was divided into phases which started from Maturity Assessment and ended at system deployment. It initially began with a POC of 1-unit (Naphtha Splitter) and later rolled out to the entire refinery.

Outcomes / lessons learnt

- Seamless integration.
- Document digitisation.
- Intelligent drawings.
- Integrating siloed systems.
- Reduced maintenance and inspection cost.
- Regulatory compliance.

Oil and Gas Digital Twin Case Study

Client profile

Global Oil and Gas major.

Client challenge

The digital twin programme promises to deliver a breakthrough in operational efficiency and working habits by creating a standardised way to describe assets and bridging technical information systems.

Solution approach

The Programme develops trusted digital twins, maintained by all disciplines, using an industry standard RDL (IOGP JIP36 CFIHOS).

The target is to standardise surface data structure between all stakeholders (trades, disciplines (engineering, construction, operations, inspections, maintenance, safety, procurement, ...) and external parties) and to define data management rules that ensure the digital twin is maintained with up-to-date data and information is shared.

Outcomes / lessons learnt

- It is necessary to perform analysis of project inputs and the Owner Operator's data model during bid phase and not after project award.
- Boost the orchestration of CFiHOS standard future updates to mitigate any impact on projects.
- EPC Contractors should start corporate initiatives to create and implement their own data model (pre ITB).
- Owner Operator should share metadata details (considered as sensitive information) before contract signature so as not to cause delay in the IM structure.
- It is important to guarantee a seamless handover throughout the lifecycle of the project.
- Industry standard adoption paves the way to an open and collaborative model.

Mining Digital Twin Case Study

Client profile

Global mining group on a journey to digitally transform its operations. Part of this journey is improving the use of data to make better and faster decisions in the field.

Client challenge

The client has little visibility into efficiency and productivity metrics during a shift. This means operators must rely on verbal communication or wait until the end of a shift to receive information. As a result, value is lost across the mining value chain.

Solution approach

The solution implemented provides real-time reports on productivity at the client mines, sending alerts to supervisors and controllers when productivity outputs deviate from plan. The digital solution has been scaled from a pilot project in 2015 to an additional 12 iron ore mines to connect and optimise the value chain across these sites. Fifteen unique users per shift (that's 30 users per day) at every site will receive real-time operational insights via this app. With this data at their fingertips, they can make informed decisions in the field in real time, positively impacting performance, and growing revenues and efficiency.

Outcomes / lessons learnt

Alerts and visualisation

- Provide users with contextualised data, to act quicker and smarter.
- Use case driven – provide solutions to key problems or opportunities.
- Create a foundational digital platform that will evolve with the business.

Digitalise knowledge

- Extract and formalise "tribal knowledge" as structured data.
- Start developing a knowledge graph with structured and unstructured data.
- Develop platform and governance to scale.
- Embed insights.
- Enrich contextualised data with tailored insights (descriptive/predictive analytics).
- Run total system optimisation (human and machine).
- Governance and platform integrated with operating procedures.

Cognitive factory

- System recommends appropriate and optimal action (prescriptive analytics), combining human + machine response.
- System continues to learn and evolve.
- Structured workforce / data science governance to develop use cases and insights.

Closed loop autonomy

- Self-learning, autonomous closed loop systems designed to sense, comprehend, act, and learn, human behaviour.
- Operators' role and skills evolving focusing on complex activities and system evolution.

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Produced in conjunction with Cohesive and Accenture