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# Digital Twins: The collaborative future of rail design

Amey Consulting White Paper
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# Introduction to the team

## Dan Smith

CEng, IMechE

**Engineering Director, Amey Consulting**

Dan is an experienced Engineering Director with 20 years in the rail engineering consultancy industry with a CEng in Mechanical Engineering. Dan has led Rail infrastructure Innovation projects using novel methods and materials, from proof-of-concept TRL3 through to demonstration TRL 6 and into commercialisation.

With a strong focus on Digital Engineering, for modelling and simulation, to solve rail infrastructure challenges, Dan is currently working on the Core Valley Lines Transformation Programme.

## Mark O'Neill

MSc, CEng, FIRSE

**Technical Director – Railway Signalling, Amey Consulting**

Mark is a Signalling Engineer with over 30 years' experience on the railway. At Amey, Mark is responsible for signalling technical assurance and innovation, engineering management on critical projects, and development of the new Hima PLC and the Network Rail ETCS Level 2 solution.

Mark has worked in all aspects of signalling design and application throughout his career, from feasibility to commissioning, specialising in system integration and design management from client and contractor perspectives.

## Mark O'Connor

MIAM

**Rail Market Director, Advisory and Analytics, Amey Consulting**

Mark is a Civil Engineer by background with over 15 years' experience in managing complex infrastructure portfolios, as both a client and a consultant. Mark started his career with Network Rail where he led the development of innovative asset management strategies on high-speed railway infrastructure, such as HS1, as well as major projects delivery for the Thameslink Programme, a major commuter route through central London.

Mark is responsible for growing the Advisory & Analytics rail portfolio, focusing on expertise in data science and asset management.

## Joe Collis

MA, MSc, PhD

**Head of Digital Consulting, Advisory and Analytics, Amey Consulting**

Joe is an Applied Mathematician by training with over 15 years' experience supporting complex decisions where there is uncertainty. Throughout his career, Joe has developed cutting edge computational and mathematical models across a variety of engineering and clinical applications.

At Amey Consulting, Joe leads on data-enabled business improvements across Amey's key markets.

# Contents

# Introduction

The UK government's vision is to position the UK at the forefront of digital technology. It is overseeing the development of a nationwide information management framework connecting smart virtual representations (digital twins) of UK infrastructure to promote better outcomes from design and building projects.

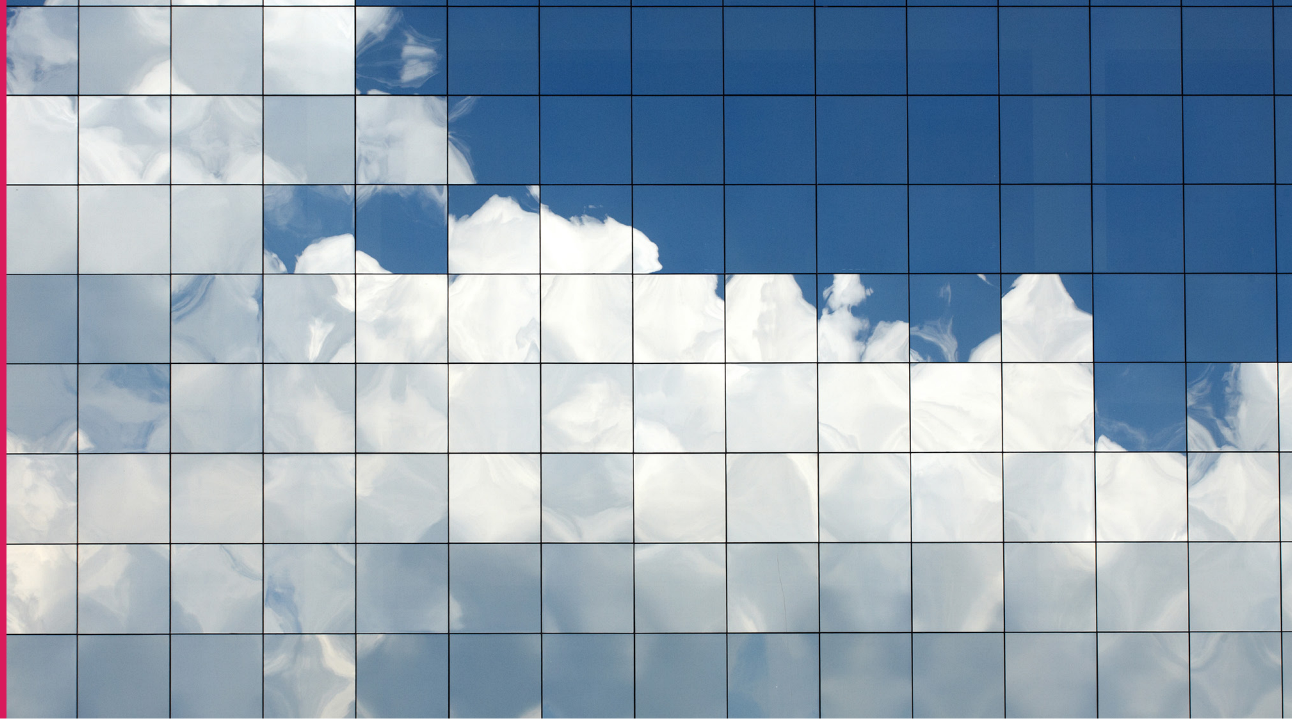
Network Rail and its successors face the enormous challenge of renewing the UK's ageing railways, particularly signalling systems. It is generally accepted that without a step change in the way new projects are designed and developed, it will be a struggle to keep the railways sustainable.

In line with the government's aspirations, Network Rail aims to exploit synthetic environment (SE) technology to improve and streamline engineering and construction projects. As a first step, it has issued an open invitation to its supply chain to develop the tools and processes needed to create a virtual design platform accessible to all.

## This document:

- Examines the state of SE technology, its future potential, and the various ways it might benefit rail infrastructure projects
- Includes a detailed look at digital twins and their potential to transform engineering design
- Asks what has to happen in order for suppliers to respond effectively to Network Rail's call.

# Context and background: a digital world



Physical simulation models have been used for decades to support decisions in the real world. One of the most famous examples is the ill-fated Apollo 13 mission; physical spacecraft simulators were used to test solutions before they were deployed in real time on the space craft. With the knowledge that all procedures had been tested thoroughly on the ground simulators, the astronauts in space felt assured they could apply them. In the end they did, and landed safely back on Earth on Friday, April 17, 1970.

Digital technology allows this approach to be taken one step further. We now have the potential to link digital simulations (synthetic environments) to real-world operations in real time (digital twins). This allows for prospective changes to be simulated, tested and approved safely in a virtual environment before deployment in the real world.

The government, in partnership with industry sector leaders and academics, is seeking to drive improvements in the UK's infrastructure through the introduction of innovative digital technologies. Tools and techniques already well advanced in sectors such as aerospace and defence are migrating to construction and infrastructure, including road and rail networks. In particular, there are active moves to exploit the potential of synthetic environments and digital twins to transform design and procurement, product testing and validation, operational performance, customer satisfaction and whole-life asset management.

## Synthetic environments and digital twins

A synthetic environment (SE) is a realistic computer simulation that allows a high degree of user interaction. The concept encompasses a wide range of applications from dynamic 3D visualisations to virtual modelling, calculations and testing.

A digital twin is an advanced application of a synthetic environment. It is a realistic digital representation of a physical entity, such as a building or railway line, which not only looks but behaves like its real-world counterpart due to the rule set applied to the model. Depending on the level of detail, complexity and built-in intelligence, a twin can be used to replicate operations, evaluate infrastructure and model the effects of change within the virtual environment as if it were happening in the real world. Mathematical and computational tools can be embedded into the simulation to automate calculations and design processes.

In its most advanced form the twin has the capacity to learn, as data derived from the condition and behaviour of the original infrastructure is fed back to the model. Artificial intelligence techniques ensure the twin adapts the rule set based on the data provided and becomes ever smarter, creating a powerful tool for design, diagnostics, problem-solving and 'what if' scenarios.

This capability means digital twins can be used to support decision-making in design, construction, operation and decommissioning. Different approaches to setting up a new system can be simulated and tested, and the computer algorithm will identify the decisions that provide the best results.

It is a proven technology. Rolls-Royce, for example, created an early form of digital twin two decades ago when it created virtual digital models of its engines designed to operate like the real thing. Comparing the performance of the virtual and physical engines identified variations which helped to pinpoint faults. Data from the physical operation of the engines was fed back to the digital twins, enhancing their modelling accuracy and reliability and helping to improve future engine designs by honing the rule set for design simulation. By applying a mathematical algorithm that learned automatically through experience and data input, the simulations ultimately achieved a high degree of accuracy in predicting problems.

Digital twins are already used in construction and facilities management for limited tasks such as design optioneering, asset condition monitoring, fault detection and similar. But rapidly evolving information, communication and visualisation technologies are opening up a much broader range of possibilities with far-reaching implications for the management of the UK's infrastructure.

Potential applications in the rail environment include the design of signalling schemes, condition monitoring of assets, simulation of train movements against proposed timetables, and modelling of 'what if' scenarios to assess the effects of change. However, no single company has the capacity to bring this technology to market. Realising these capabilities requires a committed response from the whole industry – including, crucially, the supply chain.

## Digital Britain

The government aspires to position the UK at the forefront of the digital future. In 2018, the Department for Business, Energy and Industrial Strategy collaborated with the University of Cambridge to set up the Centre for Digital Built Britain (CDBB). The CDBB runs the National Digital Twin programme (NDTp), an initiative whose key objective is to support the development of an 'ecosystem of connected digital twins to foster better outcomes from our built environment'. It is estimated that this resource could be worth almost £7 billion per year.

The NDTp is working to build a nationwide information management framework to connect digital twins planned or under development in the construction and infrastructure sectors. A set of values, known as the Gemini principles, provides guidance for best practice and the secure sharing of data. A Digital Twin Hub has been set up to provide advice, support and resources for businesses and organisations working on digital twins.

Against this background, the government, Network Rail and rail industry leaders have introduced the Digital Railway Programme to modernise the UK's ageing signalling network. With much of the signalling infrastructure due to become obsolete within the next 15 years, the programme sets out a strategy to replace conventional signalling systems with a system-wide digital equivalent.

This ambitious scheme cannot succeed without the support and participation of every stakeholder in Britain's railways, from clients (notably the new public body Great British Railways, due to replace Network Rail in 2023) and train and freight operating companies to industry representative bodies and the contractors and suppliers who design, build and manage the UK's railway infrastructure.

Clients have a particularly important role to play in encouraging and supporting progress. Transport for Wales, for example, has introduced an accelerator programme to fund start-ups focused on innovation in the Welsh rail industry. An early example is Quinean, a new company which has developed a low-code machine learning platform that allows experts in different rail disciplines to deploy digital twins, test hypotheses and optimise outcomes at speed.

# Network Rail: call to suppliers

## Network Rail faces the challenge of renewing a huge body of ageing signalling infrastructure with limited resources. The problems caused by outdated and inadequate equipment are pressing. It is not just a question of reliability and safety – 'pinch points' are limiting the capacity of the network to expand.

Network Rail believes the Digital Railway Programme is a key part of the solution – replacing conventional signalling systems with modern signalling and train control technology, coupled with new ways of working, to increase capacity, reduce delays, enhance safety and drive down whole-life costs. NR's plan envisages 'targeted deployment' over the medium term, with localised digital solutions applied when opportunities arise within the constraints of its capital plan (CP).

The immediate issue, however, is tackling the burden of signalling renewals essential to keep the railways running in the short term. The scale of the task means that the conventional procurement process, with its costs and extended timescales, cannot keep pace. Network Rail seeks to streamline future signalling projects through the creation of a synthetic environment that will function as a virtual design platform accessible to all its suppliers.

## Benefits of a synthetic environment

In an early supplier engagement webinar at the start of 2021, Network Rail announced its vision for future procurement, stating: 'A data-driven synthetic environment will provide the opportunity we need to break away from highly customised and bespoke projects and products, integrate our processes, and deliver faster, safer, and more reliable schemes.'

Developing a signalling scheme in a virtual environment equipped with advanced modelling, computational and visualisation capabilities, and infused with machine intelligence, offers a number of benefits to both designers and Network Rail.

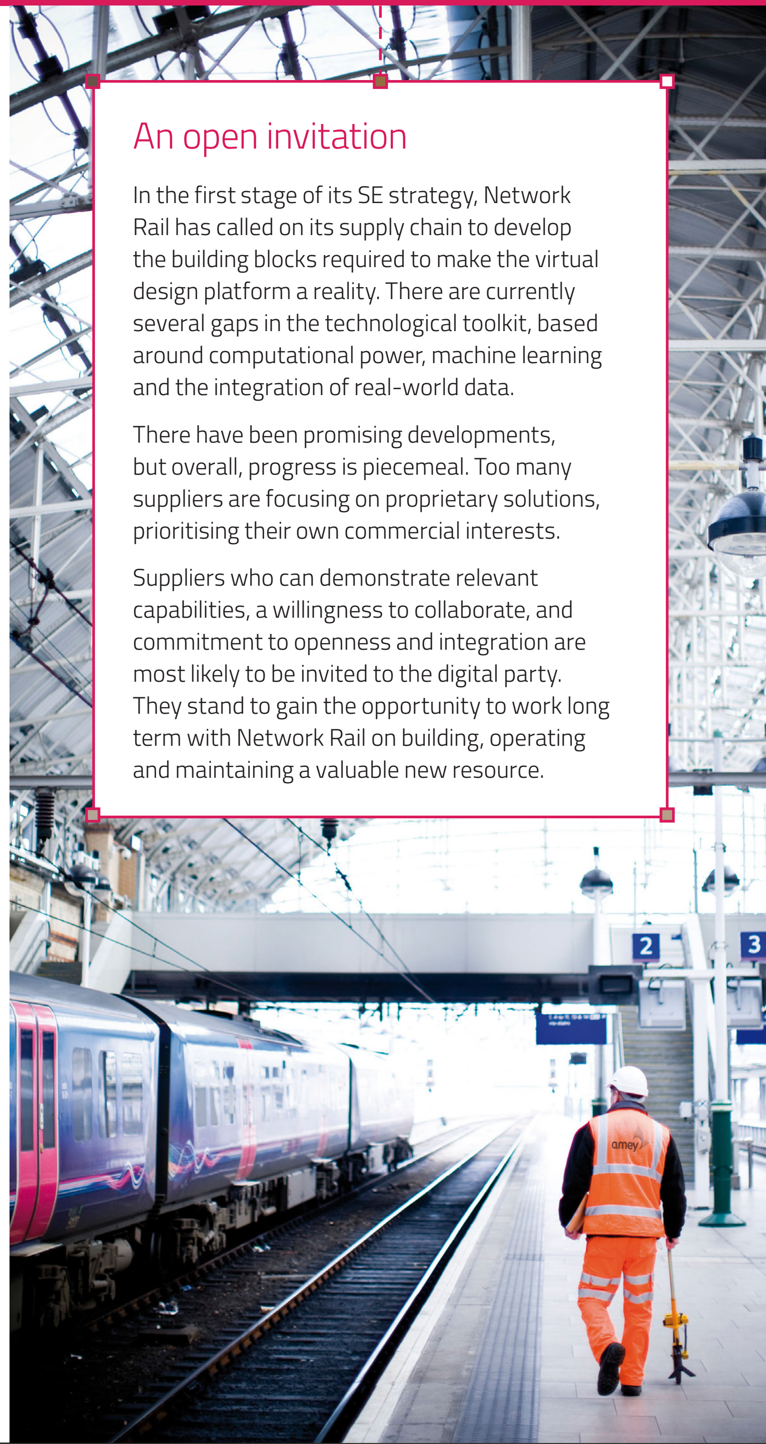
- The design process would be facilitated by automated processes and calculations, with rules, standards and compliance checks automatically applied. The design could be tested and assured in the virtual environment, shortening the time required to conduct actual tests on site.
- Products from different suppliers could be integrated and validated in the virtual environment, reducing the risk of incompatibilities when specified for a project and contributing to a live knowledge base of tested, approved products.
- Data generated by the design and product testing process could be fed back to the SE to inform future projects. Once a scheme is live, operational data could also feed back, further enriching the SE and its decision-support capabilities.
- Components within a model could be asset tagged and linked to O&M manuals, helping to streamline the asset and facilities management functions.
- By basing the design platform on open standards and COTS (commercial off the shelf) components, quality would be improved and costs minimised. Designers would be free to specify the best available products on the market.
- In time the synthetic environment could evolve into a full-scale digital twin of the railway, a powerful resource for high-level tasks such as verifying and validating data, optimising train movements and modelling the effects of change. The twin would facilitate the shift from conventional to digital signalling, providing designers with sophisticated tools to plan and visualise the new equipment configurations required.
- There are also positive implications for climate change and sustainability, where environmental impacts are factored in. For example, the twin could be asked to model and compare the effect of different train paths on carbon emissions.

## An open invitation

In the first stage of its SE strategy, Network Rail has called on its supply chain to develop the building blocks required to make the virtual design platform a reality. There are currently several gaps in the technological toolkit, based around computational power, machine learning and the integration of real-world data.

There have been promising developments, but overall, progress is piecemeal. Too many suppliers are focusing on proprietary solutions, prioritising their own commercial interests.

Suppliers who can demonstrate relevant capabilities, a willingness to collaborate, and commitment to openness and integration are most likely to be invited to the digital party. They stand to gain the opportunity to work long term with Network Rail on building, operating and maintaining a valuable new resource.



# Amey's response

Amey Consulting welcomes and supports Network Rail's plan to build a synthetic environment for the design, development and testing of signalling renewal schemes. As a long-time provider of engineering design and infrastructure management services to the rail industry, we believe there is strong value in the creation of an open, integrated design platform and digital twins to facilitate the modernisation of the network.

Network Rail is looking for partners to complete the toolkit needed for the first phase of SE development. It wants to see not just good ideas but proof of concept – evidence of concrete results that can be applied to current projects and future work streams.

We are working to build on our existing capabilities to meet the new requirements, such as more powerful tools to automate design processes. We are developing our proficiency in modelling train movements based on realistic simulations. Our strategic consulting team is exploring ways to combine our engineering know-how with our data handling and analytics expertise to develop smart, data-driven digital twins.

We are keen proponents of collaboration and are working with partners to enhance our digital offerings. For example, we are working with universities on mathematical models for checking and testing designs as well as improved virtual reality interfaces for simulations.

# Signalling design in a synthetic environment

There is much discussion about the capabilities of synthetic environments and digital twins, and their potential applications in the real world. It is true that with the introduction of sophisticated techniques such as mathematical modelling and machine learning, digital twins can become an extremely powerful resource, able to support decision-making at the highest strategic level.

However, it's important to be realistic about what the technology can actually achieve in practice. While it is tempting to experiment with cutting-edge new technologies, purely to see what is possible, developing a digital twin is a complex and costly exercise that should be driven by a clearly defined outcome.

It is not possible to create a computer simulation of a real-world scenario – say, a station, depot or railway line – that is accurate in every detail. Even with the latest technologies, embedding all the information and running all the computations needed for every element of the model to behave like the real thing is simply impractical. It's important to start with a clear idea of the reason why there is a need for the twin, the problems it must solve and the information it is required to provide. Detail is only added where it supports the decision-making process.

Signalling design is a good example of how a well-conceived synthetic environment can deliver real benefits. This is partly because the process is highly prescriptive, governed by rules and calculations that lend themselves to automation and machine learning.

The current design approach tends to begin with 'pen and paper and people's brains', with information gathered from a range of sources. These include track surveys, asset information, product information, industry safety and compliance data, and specialist knowledge derived from the designer's own experience. An Amey project also benefits from our staff's real-world rail knowledge built up over years of collective practice.

The layout of signalling equipment depends not just on the geometry of the track, but rules based on factors such as rolling stock, line speed, braking distances, headways and signal overlaps. Once a plan has been drawn up, a control table is generated specifying the interlockings between the points and other signalling controls as well as associated circuitry. The completed designs undergo extensive validation and testing to assure their safety and viability.

Signalling projects are multidisciplinary, requiring input from track, electrical power, telecoms and often civil engineering teams. As the design develops, interfaces with the related disciplines must be managed, with procedures put in place to avoid clashes and ensure seamless integration. Design review meetings are scheduled to monitor progress, address issues, validate the design and gain the necessary approvals.

The process is time-consuming and requires skills that are in short supply, so it is no surprise that Network Rail and many suppliers are seeking ways to streamline and automate the work. The digital solutions developed so far, however, tend to address specific aspects of the process – generation of the control table, modelling of the movement of trains through the signals, or testing and validation of the design. The scheme is still likely to begin with a sketch on paper.

Building information modelling (BIM) is proving useful in sharing data and facilitating design integration via a (static) federated model. But what is lacking is a platform that allows the signalling plan to be conceived, developed, simulated, tested and assured, all in the same virtual environment.

This is where a digital twin would come into its own. A realistic model of the site – a station, depot or junction, for example – complete with asset information, built-in computational processes, machine intelligence and access to big data, would place a powerful tool in the hands of the designer.

It would not only save time and work by carrying out standard calculations, generating code for the interlocking diagrams, and generally applying the relevant rules, parameters and compliance checks, it would improve the quality of the design by allowing the designer to simulate and evaluate different layouts, equipment configurations and control scenarios. Testing and validating the design in the virtual environment would significantly reduce the time required for possessions and on-site testing. The installation team could be assured of working with a viable plan and proven equipment.

Once built, the digital twin could be run alongside the real-world installation, growing smarter as data from train and signalling operations are fed back into the model, adding to its value for future design projects. Over time, localised digital twins could be upscaled and connected to build the kind of industry-wide digital ecosystem envisaged by the Centre for Digital Built Britain.

In conclusion, implementing signalling design in a synthetic environment is not only practical and feasible, it should become the standard design process, offering obvious benefits to Network Rail, engineering designers and the industry as a whole. The missing technological components – computational power, machine learning, the integration of real-world data – are likely to be resolved sooner rather than later. The migration of the design process to a digital environment might also present an opportunity to review current rules and standards to ensure they are still fit for purpose.

Network Rail has set out its roadmap with the Digital Railway initiative. The will to innovate is not in doubt. The issue is whether suppliers can collectively work towards the open platform and design protocols that will empower Network Rail to 'break away from highly customised and bespoke projects and products, integrate our processes, and deliver faster, safer, and more reliable schemes'.

# What next?

The establishment of the virtual design environment as prescribed by Network Rail is the first stage in its overarching strategy for the modernisation of the railway, spearheaded by the renewal of the signalling and train control systems.

However, the possibilities extend far beyond design. As the capabilities of digital twins develop, they will be able to provide real-time data for business decisions relating to railway operations, infrastructure development, asset management and the realisation of the Digital Railway.

## Operational improvements

The ability to model in real time the movements of trains around a digital twin of the railway network has great potential to improve the safety, efficiency and reliability of train services. Operators would have the capability to model different scenarios in response to changing conditions on the network, allowing them to identify in real time the operational decisions that will produce the best outcomes.

In terms of planning, operators could use the twin to test proposed timetables and journey routes to maximise throughput. Environmental factors such as the carbon implications of different options could be included to support the sustainability agenda.

## Strategic asset management

By embedding advanced data handling and analytical capabilities into a digital twin of a facility or location, the twin becomes an important tool for enterprise asset management. Each asset in the simulation would have a unique identifier, and the assets would connect and interact as they would in the real world. Fed by a stream of live real-world data, the performance of each asset could be monitored in real time. Factors such as failure rates could be analysed to help predict future problems.

Any change in the physical world – such as an alteration to the speed and frequency of trains – could be modelled to test the ripple effect and the impact on asset condition and performance. This could be linked to maintenance programmes, which would automatically adjust to suit the new conditions. The information could also be used to support and inform future investment strategies.

## Digital signalling

The ambitious Digital Railway programme envisages a phased move from conventional signalling to digital signalling, in which traditional location-specific coloured light signals are replaced with radio signals into the driver's cab.

Work has already begun on equipping Network Rail trains with ETCS (European Train Control System) in-cab signalling capability. Future phases will focus on adjustments to lineside signalling equipment and interlockings. Currently digital signalling works are implemented by discrete packages in route or region, and the wholesale conversion of the UK system to radio-controlled signalling seems a long way off. A key issue is managing the interfaces between digital-ready and conventional sections of the railway.

It is easy to see how the availability of a digital twin of the network (or sections of it) would be beneficial, and not just to accelerate scheme design. Digitisation is likely to have a significant impact on drivers, and the twin could be used to create a key training resource. For example, it could provide a realistic visualisation of what the driver would see as the train progresses through the digital signalling system in real time, including what happens in the cab – how messages are received, and how the train acts upon them.

# Conclusion

The UK rail industry is on the cusp of a digital revolution, opening up extensive opportunities for improvement and innovation. But bringing about change in an old industry weighed down by an ageing infrastructure, legacy equipment, outdated processes and rigid working practices will be difficult and riddled with pitfalls.

Now is the time to establish the platforms, protocols and working structures that will underpin modernisation and the move to digitisation, creating an open development environment that suits the needs of the industry rather than narrow commercial interests. This will inspire and educate the digital engineers of the future, as well as tap the knowledge of an older, experienced generation before it is lost to the industry.

The capabilities of synthetic environments and digital twins are evolving all the time as information, visualisation and communication tools continue to advance. Digital twin technology is already well established in sectors outside the construction and infrastructure sector. The government, Network Rail and other industry leaders wish to see this technology applied to rail infrastructure development.


Network Rail requires dependable partners committed to its objectives and values to help realise its vision. It needs suppliers willing to invest, to fill the technology gap and work towards open standards accessible to all. The push for reduced costs and streamlined processes will not be served by suppliers seeking to retain control of the systems and products they develop, as has been common practice up to now.

Meeting Network Rail's aspirations requires input from multiple participants. Network Rail will favour proposals that allow data to be freely shared and equipment that connects via open interfaces. Its plans will best be served by a competitive development environment with participants striving to deliver the best solutions for the industry. However, within that environment Network Rail will want to see productive collaboration, with partnerships forming to develop creative synergies.

As an experienced supplier to the rail industry, Amey Consulting welcomes Network Rail's plans for the industry and is actively responding to the call for a demonstration of capabilities. We believe we can add real value to the development of a synthetic environment and digital twins in a rail environment – particularly in the domain of signalling.

Uniquely among rail suppliers, we have experience in all stages of railway management, from signalling and track design, testing and installation to the operation of train services, maintenance and whole-life asset management. We intend to bring our engineering, design, infrastructure and data analytics expertise to bear on creating digital twins that produce real benefits and answer real questions. Where there are gaps in our capabilities, we will collaborate with partners to develop viable, innovative solutions.

With our commitment to openness and integration, and readiness to learn and work with others, we are well placed to tackle the blockers and barriers likely to impede the change process.

## For more information:

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## About Amey

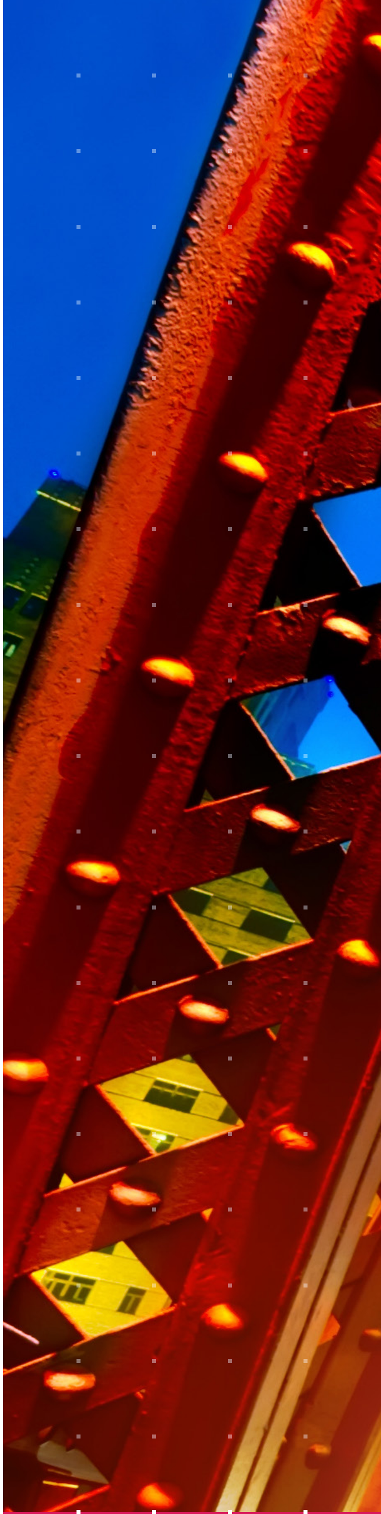
Amey is a leading infrastructure services and engineering company.

We are at the heart of modern Britain, helping the economy to grow by designing, maintaining and transforming the nation's strategic assets.

Our 14,000 people are behind the critical services the country relies on every day and we each take personal pride in our public service.

Our unique engineering and operations experience, together with data driven insight from our consulting business, delivers better results for our clients.

We are trusted partners of Government – both national and local – managing assets and complex projects that are vital to the sustainable growth of the country.



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