ARUP

Transformative Rail

The issues shaping the future of the industry

Arup Rail

From a nation's economy to a single commuter journey, rail can transform lives, businesses and communities. In a world wrestling with climate change and ever-increasing demand for mobility, rail is also a more sustainable choice.

Rail projects demand a complex mix of skills and insights – from initial strategy and economics, through to engineering, people-centred design, operations and asset management. That's why our technical expertise is always backed by sharp strategic thinking, whether we're optimising existing services or designing new railways.

We help our clients:

- Design quality infrastructure and experiences for people and communities
- Deliver major programmes and develop high performing organisations
- Integrate complex new technologies and systems
- Unlock financial value for investors, asset owners and operators
- Optimise performance and value from existing and new assets

Across all these services we bring ambition, commitment and a focus on the future. That's how we deliver real transformation – unlocking the true potential of rail for clients and communities the world over.

Find out more about our rail business by contacting rail@arup.com.

About Foresight, Research and Innovation

Foresight, Research and Innovation is Arup's internal think-tank and consultancy which focuses on the future of the built environment and society at large. We help organisations understand trends, explore new ideas and radically rethink the future of their businesses. Research has played a fundamental role in defining how we anticipate and leverage emerging business opportunities. Applied research continues to underpin our ability to address our clients' greatest challenges.

Find out more about our research at research.arup.com.

ARUP

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Introduction

TC Chew
Global Rail Leader
Arup, London

Our industry is facing pressures like never before. Rising demand, the arrival of the digital passenger, the call for high speed systems, the need for more efficient asset management; the list of operational priorities never stops growing. In our earlier *Future of Rail 2050* report, we took an in-depth look at the macro-trends that are shaping the industry: urbanisation, climate change, population growth, demographic change; smart and integrated mobility. This new publication switches focus from trends to relevant solutions for railway systems that are fit for today's demand and tomorrow's opportunities.

Around the world, rail has never been more popular or relevant. As city populations grow, the impacts of climate change bite, and sustainable development becomes imperative, rail is the mode of transport best-placed to support the transitions we need. The challenge for the industry in all its forms – operators, asset owners, regulators, suppliers, advisors, investors and governments – is how to turn this momentum into consistent, transformative progress, and ensure passengers' participation in the process.

Human-centred

Start with the passengers. Meeting their transport needs in a way that's as quick, easy, reliable, affordable, inclusive and comfortable as possible is critical to success. Staff across the rail industry also need to feel inspired and supported to deliver the quality of service everyone wants to see. And we need to consider the expectations of communities in and around the rail network, if our investments are to translate into greater prosperity and social wellbeing.

These are ambitious goals, requiring a 'systems thinking' approach that considers the whole rail equation: no more short-term or siloed thinking. It's time to integrate rail systems within the wider city and mobility agenda too. Transformative outcomes will require nothing less.

Sustainable development

Rail has always connected people, places and opportunities. From its ability to drive economic growth and revitalise communities, to its energy efficiency and low carbon footprint, rail has a critical role to play if the aims of the United Nations' Sustainable Development Goals are going to be met.

But there are still some difficult historical issues and current trade-offs to acknowledge and manage. Electrification of old diesel services is expensive. A transition towards zero carbon railways won't be easy to achieve. And with increasingly extreme weather and rising sea levels, a resilient railway has to take account of new and costly vulnerabilities. Understanding how to invest in these priorities has never been more important.

Thomson-East Coast Line -
Woodlands Station, Singapore

Digital evolution

We all recognise digital's potential, but realising it at scale, within existing systems is hard. In this report we explore the best approaches, prioritising where digital innovation can add the most value, and truly transform day-to-day operations.

In a complex, safety driven sector like rail, applying new technology can have major consequences, particularly when new systems can take years, sometimes decades, to complete. We look at how to design-in resilience and adaptability, so that investments remain relevant and valuable. At base, it's about taking a far-sighted approach to new technology, staying focused on the human-centred principles that underlie all successful digital innovations.

These challenges and many more are the subject of this publication. Drawing on the expertise of rail specialists, inside and outside our firm, it brings together the insights, debates and discussions that are shaping today's rail agenda. We trust you will find it informative, and a worthwhile contribution to the ultimate goal of helping rail fulfil its transformative potential.

Grand Central Station, New York

Chapter 1

People and the customer experience

Delivering excellent customer service: a complex balancing act

The popularity of rail travel continues to grow, with a 91% rise in global rail passenger activity over the last two decades.[3] New lines are being opened, expanding connections and transforming local communities. Developing countries are driving this trend and shifting the geopolitical setting for rail. To give an impression of the scale of this shift, it is estimated that Indian railways will account for nearly 40% of total global rail activity by 2050.[3] In 2017, passengers travelled over four trillion kilometres by rail, representing approximately 8% of total transport passenger-kilometres.[4]

Delivering a high-quality customer experience is therefore increasingly important, especially if we are to encourage more people to choose trains over cars. However, the definition of a quality experience varies (see ‘People first: but how?’, p. 12). For customer satisfaction, people – passengers, staff and communities – should be at the heart of decision-making. But expectations are not always easy to balance with functional and operational requirements. A more integrated approach to planning rail infrastructure and operations can help the industry to provide the high-quality service that passengers demand.

The definition of a journey is changing

From shopping for groceries to booking holidays, services generally have become more convenient, allowing people to make purchase decisions on the go. Rail travel should be no exception. New thinking needs to reflect the whole journey: from the moment a decision to travel is made, to arrival at the destination. This requires enhanced collaboration with existing and new industry players.

Enabling truly seamless mobility is only possible by moving away from the conventional siloed approaches, towards integrated transport strategies. Harnessing the individual benefits and complementary characteristics of the various modes of transport will help achieve an integrated transport strategy. This approach can solve one of the big challenges that rail systems are facing for customers and goods: the first/last mile conundrum. Key to this is a digital layer that will help to create a holistic view of the transport system, making seamless mobility possible. However, policy and economic incentives will be needed to facilitate implementation and coordination.

New frontiers for rail

The tremendous amount of data and digital technology now available to help customers understand and personalise their entire journeys brings both opportunities and risks. New skills and new investment are needed. Privacy is inevitably the traded commodity in the effort to increase convenience, but people should be given a choice (see ‘Prior to boarding, please accept the cookies’, p. 19).

Communication has increased and become personalised thanks to technology, but effective physical wayfinding design is still essential to ensure clarity and support safety (see ‘Accessibility, safety and security should go hand-in-hand’ p. 28). Getting this balance right is one important factor in creating better, more people-centric railways. The good news is that with the right approach this goal is within our grasp (see ‘Positive change through developing leaders’ p. 20). ■

At a glance

Increasing inclusivity
Improving people’s rail experiences for all: passengers, staff and communities — whatever their needs

Involving everyone
Engaging stakeholders from the start to improve project outcomes

Making journeys seamless
Creating improved connectivity with diverse modes of transport

Creating destinations
Bringing amenities and communities together with horizontal and vertical integration

Harnessing smart technology
Balancing benefits with privacy in the quest for easier, more comfortable, and safer joined-up journeys

Enhancing the experience
Creating more enjoyable rail environments with art and green spaces

Future-proofing
Recognising changing passenger needs and the importance of good management for long-term resilience

Opposite
Canary Wharf Station, London

In conversation

People first: but how?

Experts from Canada and UK discuss what customer experience really means to the rail industry, how to ensure customer-centric designs and how to deal with people's most sophisticated needs.

Matthew Hudson
Head of Strategy and Technology and Data
Transport for London

Nille Juul-Sørensen
Global Architecture Business Lead
Arup, Toronto

Sean Schofield
Senior Innovation Adviser
VIA Rail

Charles Ormsby
Senior Engineer
Arup, Montreal

There is a lot of talk, in rail and in transport systems in general, about customer experience. What does quality customer experience mean to you?

NJS I believe rail systems and public transport should know no borders. To me, customer experience is about travelling through quality spaces in a nice, logical and seamless way. When you are in a transport system, you should also have a spice of something extra that you don't have at home; something that makes you think, what time of the year is it? What time of the day is it? Things that add sparkle your life. It's about connecting you to a broader urban fabric.

SS To deliver customer experience you must start by exploring what experiences fit customer needs and drive differentiation. There are a lot of vectors for the transformation of customer experience: employee experience, operational staging of assets, and use of blended space. A trend we are seeing is traditional space (concrete, steel) being blended with natural plant life and digital layers (often visual). With augmented reality, these environments become even more dynamic. Overall, I expect a lot change in the demand and supply of experiences, even in the short term.

MH I come at this from a slightly different angle, representing urban transit that is set up by the state to provide a service for all. I'm definitely trying to put myself into the shoes of our customers. At TfL we have a phrase, 'Every journey matters'. This pulls us away from thinking in large numbers like 'four million journeys a day', to a point where we are focusing on the individual, and here the key is … I'm going to call it 'frictionlessness'. We want to make journeys as easy as possible. That involves a range of interventions, from consistent signage to paying with your bank card, to excellent maps. It also includes journey-planning apps that work for everyone and integrate all the public transport modes in a city, including walking and cycling. Certainly, for us there's a slight element of utility here and I don't say that with shame. We want to get people through stations as quickly as possible and out on their journeys; providing a high-frequency rail service. This defines to us the frictionless flow and this is the building block on which many other things can be built.

How do we keep up with what people want so that we can consistently deliver a good customer experience?

MH Surveys are not the answer. Ideally, every single person who's travelling in London would tell me who they are, their intentions, their preferences, the journey they are making. The more data I have, the more chance I have of making better operational decisions and meeting customer needs. But getting access to this type of data is still a challenge – how do you collect it, and how do you anonymise it and respect customer privacy? Engaging with customers will also allow us to manage their expectations and say, yes, the Tube train will be crowded for the next hour, so don't expect anything else.

SS You have to be very careful trying to anticipate what people want. It's about trying to understand the underlying fundamental needs of different customers. The customer is often the wrong unit for analysis (i.e., their attributes: age, gender, occupation, etc. do not cause any given behaviour), but their underlying needs not only cause specific behaviours but are highly stable over time.

It is important not to overly focus on a single means of fulfilling a need, because you become really vulnerable to being quickly outdated or displaced.

MH Some of the expectations may be undeliverable for various reasons, such as cost. The Tube line will never run directly to your door. But understanding our customers helps us to come up with the right messaging and to some extent influence their choices.

SS In any context where you are trying to nudge behaviour, you need to think about the path of least resistance. You have to consider what behaviour will people default to and what behavioural incentives or disincentives can be used to tip the scales towards the desired outcome(s) at any stage in the journey.

How can we translate people's needs into physical designs?

NJS What I do is visit stations. I walk around and take trains and walk in and out of stations. When we do new stations in a city, I spend days in the system, finding out what's working and what's not working, how people behave in the system – because a lot of things are cultural. It's about observing and finding out what's happening elsewhere. We can also learn a lot from other industries, such as aviation. The idea of adding shopping malls to stations, for example, came from airports. How to spot the next thing that passengers didn't know they needed is a different question.

MH I want to share two examples on this topic. First, when we designed the stations for Docklands Light Railway in London, we worked out how to balance safety and cost through a more open design of the stations. By design, we saved the money that would have gone into the operational staff that would have been required to make people feel safe on the platforms. The second example is the extension of the Northern line to Battersea Power Station in London, which rather than a response to a particular set of customer demands, materialised due to a set of favourable circumstances: a keen investor, a good business case, and perfect political timing. It's a balance between what future customers want and need, and business opportunities.

SS In any context where you are trying to nudge behaviour, you need to think about the path of least resistance. You have to consider what behaviour will people default to and what ▶

Commuter at Kobenhavn H Station, Cityringen, Copenhagen

"At TfL we have a phrase, 'Every journey matters'. This pulls us away from thinking in large numbers [...] to a point where we are focusing on the individual..."

behavioural incentives or disincentives can be used to tip the scales towards the desired outcome(s) at any stage in the journey.

MH An ongoing challenge is how to create attractive entry points to the rail space, persuade people to come and experience shopping or restaurants – be it part of the journey or not at all! Think of the gardens at Atocha station in Madrid or the restaurants around King's Cross. Whether it can or should continually adapt, I'm not sure. There has to be flexibility, while recognising it takes time to invest in it. It's a difficult balance to strike, but it's worth exploring.

Speaking of balance – how can we best respond to customers' sophisticated needs without compromising on operational performance? Does smart always mean complex?

CO This is an element where partnering becomes critical. There's great value in leaving transit agencies to do what they do best, which is moving people from A to B. Partnerships could bring additional layers of services and experience, while ensuring that your core offer is not neglected. Mobility as a service, for example, is a case where you start to leverage different players and let everybody do what they do best but with a common platform that's coordinated and integrated. A supporting business model for the integrated, collaborative approach is very much needed.

One of the core practices of good user-experience design is – to paraphrase Einstein – to be as simple as possible, but not simpler. I think the exact same kind of logic applies to trains and stations. A minimalist design and core service offer is what's going to win.

NJS I'm fully with you. For example, thinking about when I travel and the apps I use, where do I get help, if at all? In Oslo, they have a magnificent app for the train leaving the airport into town: it's just telling me the essential information I need: when the trains are leaving, what my options are. It's so simple. They're delivering exactly what I want. Smart, in some cases, is not sophisticated at all: it's just doing exactly what you ask it to do and nothing else.

MH Again, we should not forget the cost challenge. Let's take mobile phone coverage on the London Underground. How can I cover the expense of installing that radio network? I'm not going to earn huge amounts with it, but it does help my customers. There's always that practicality of getting access to the investment. What worries me are some aspects of operator-customer interaction, namely, if they happen using a third party's digital tools and platforms. Third parties have their own priorities and want to instigate specific customer behaviours – which may conflict with what we are trying to do. Finding a common ground and shared goals is a prerequisite to enable commercial partnerships.

SS The other aspect is how we make the infrastructure agile and adaptable over time. Even how we fulfil fundamental needs is likely to change significantly and frequently over 50 years. Being able to build flexible, modular, multi-purpose spaces will determine how successful we are in adapting to the future. This is a challenge, as we typically operate with pre-existing assets with no real flexibility for multiple rebuilds. Recognising these limitations can teach us how to build better spaces and save future generations from facing the very same challenges.

MH To come up with a good business model we would need to fully understand how cities operate and make sure everyone is paying their fair cost for the services they use. We're using market mechanisms to incentivise behaviour, but how do we ensure fairness and equity across all users? It's a great space to research further.

SS It's going to be really interesting to see how policy might play a stronger role in setting boundary conditions, so that when business models for mobility as a service are viable, they're actually viable in the best interest of all travellers. ■

Changi Airport, Singapore

“At HS2 we want to be the market leaders in developing the standard for inclusivity and accessibility as part of the customer experience. We leverage technology to simplify the process: from planning, to booking, to arriving at the station and accessing the platforms, to boarding the train and finding your seat. Only by mapping the entire journey can we create a seamless experience for all our customers.”

Johannah Randall
Associate, Contrax
(Former Head of Station Operations
High Speed Two Ltd)

91%

increase in global rail passenger activity in two decades

4 trillion

kilometres travelled by rail passengers in 2017

8%

of total transport passenger-kilometres are travelled by rail

Second Avenue Subway, New York City

Case study

MTA Enhanced Station Initiative Program

New York City’s Subway system is a vital public service used by an average of 4.3 million people every day. The Metropolitan Transit Authority's (MTA) Enhanced Station Initiative is a major program to reinvigorate New York City Subway stations across all five boroughs. By mid-2019, 20 stations had been transformed. The value of the program is nearly US$ 1 billion.

Station upgrades include: improved wayfinding; new and renovated station entrances; and state-of-the-art digital technologies such as real-time countdown clocks and customer information displays. Other features include: LED lighting and controls that provide brighter safer spaces; improved platform edge demarcation; and decluttered spaces.


Atocha station garden, Madrid

Relax, you are at the train station!

Alice Chan
Director
Arup, Hong Kong

Railway stations have come a long way from their origins as the points where journeys begin and end. Today, stations are multifaceted developments, bringing together multiple transport modes and much more.

As populations grow and urbanisation gathers pace, demand for convenient and accessible mobility is rising. This has seen the scope of stations expanding – both vertically and horizontally.

Vertical integration with property developments has been especially popular in dense Asian cities, but it is becoming more common in other parts of the world too. Horizontal integration is also increasing with stations connecting with features like raised footways and underground tunnel networks – encouraging 'walkability' and connectivity with the wider urban community. In total, retail, office and hospitality spaces are all becoming part of station developments, blurring the lines between transport and the city. However, this increased functionality comes at a price. Meandering corridors, tunnels and escalators can disorientate, frustrate and overwhelm travellers. Combined with stifling crowds at peak times, this often leads to unnecessarily stressful experiences, especially for older people who can often feel excluded.

One solution to these challenges is a more inclusive design approach. This sees the careful application of elements like covered walkways, travellators, spacious tunnels, benches and resting places, and proper wayfinding techniques. However, in stations around the world design teams are increasingly looking to nature in their search for an even better passenger experience.

Research shows that embedding green landscaping in stations and surrounding areas helps to create environments that lower stress levels, allowing passengers and staff to function more calmly and effectively. Other elements of a more naturally focused design agenda are effective too. These include the presence of plants and water, the use of natural colours, materials, and forms, and access to natural light and fresh air.

Recent successful examples of these techniques include the roof top gardens at Hong Kong's Admiralty Station, the tropical garden at Atocha Station in Madrid, and New York's 'Arts for Transit' initiative. These 'biophilic design' features not only improve the passenger experience. With benefits like improved air quality and increased access to natural space, they enhance local communities too.

It's time we started sharing and applying this approach much more widely.

Prior to boarding, please accept the cookies

David Moran
Associate Director
Arup, London

Across the rail sector, in any discussion about improving customer experience, the subject of digital privacy will generally be low on the agenda. Safety, security, reliability and a host of other concerns rightfully dominate the design of rail projects. Digital privacy can still be perceived as a niche topic, despite the regular flow of stories in the media about the compromise of personal details or abuse of social media data. When was the last time you read the privacy statement on any of the websites you access, even when you are explicitly prompted by the 'cookie notice' on your first visit?

Consider a train journey that takes you from A to B. Every step of the way you might be leaving a 'digital footprint' of your activity: your ticket-buying habits logged against your online account, the credit card used to pay, the CCTV that monitors the station, the ticket barriers you pass through, the on-board wi-fi, or the coffee you buy on the train with your card. Even the journey that your phone makes is electronically tracked by the mobile network and sold on to organisations (including the train companies) interested in the volumes and trends of journeys made by rail.

The risk of abuse of your personal data in these circumstances is real, as are the potential impacts if this happens. Privacy matters to people just as much as safety, security and other design attributes. This must be kept at the forefront of our minds when considering the trade-offs and compromises that ultimately shape the outcomes of a project. As examples, CCTV is meant to increase your security but inevitably reduces your privacy. Contactless payments are quick and convenient but register the data from your debit/credit card. And all those tempting rail marketing offers and discounts get a return on investment in the form of data analytics that map your behaviour and habits.

Today's railways are rightly increasing the spotlight on improving customer experience. For most people, using credit cards, wi-fi or their smartphone is seen as an inescapable convenience. But it is easy to forget that there is an implicit permission granted by the customer in these scenarios: "I will use digital technology as long as the trade-off against my privacy is acceptable to me. And how I define 'acceptable' is also my own personal decision and will change over time."

Digital technology provides opportunities to transform lives for the better. In parallel, it must offer data privacy controls to the individual, so they can 'opt in' to these conveniences to a greater or lesser degree. This means alternative ways to pay, including cash, even if that means joining a queue for a ticket office clerk. Recognising this implicit privacy trade-off means we can design railway schemes and systems so that people can quietly enjoy seamless journeys, without handing over more than they expected to about their private life.

In conversation

Positive change through developing leaders

In a highly regulated industry, based on procedures and rules, we gain insight into a very human approach to inspiring change: the Leading Customer Service (LCS). Rob Jones interviews Brian Woodhead.

Rob Jones
Director
Arup, London

Brian Woodhead
Director of
Customer Service
London Underground

Brian, how did you come up with the LCS initiative in the first place?

LCS was designed to respond to two needs. First, the industry-wide problem we face working in an operational environment: how do we evolve to meet rapidly changing societal needs when we operate in such a reactive culture?

Second, how do we make sure that London's travelling public have a better experience when using our service? We saw an opportunity to develop our leaders to enable them to respond to changing communities and business requirements more effectively.

What were you hoping to achieve when you put LCS into motion?

Let's look at London Underground (LU)'s exemplary management of the 2012 Olympics. How do you create the same passion, energy and pride that we experienced back then, but every day across multiple locations, during all possible scenarios? For instance, how do we ensure world-class customer service in a crowded station following a football match or on a freezing evening during Night Tube services? How do you take individual examples of world-class customer service and make them the norm every day, in every situation? Special public occasions create specific conditions, such as media exposure and political scrutiny.

To maintain this on a day-to-day operation requires the whole system to feel connected to the organisation's vision. We also need to understand how this pragmatically translates to consistently managing all aspects of the network to a high standard.

How do you go about creating consistency?

Acknowledging that each leader will start the LCS journey from somewhere different, we tailor the experience with the aim of all the leaders finishing in the same place, akin to the analogy of running a race 'in reverse'. In other words, leading and engaging people in a consistent way. LCS offers a series of sessions centring around topics driven by organisational data and feedback from different levels in the business.

The format is experiential and conversational; it creates the space for our leaders, who have highly demanding roles, to think differently about the way they approach their roles as leaders, managers and coaches. Leaders are given the space to take learnings and insights back to their teams. This allows them to experiment with different approaches to engaging with frontline staff and the impacts this ultimately has on customers. Categorically, this is not a training exercise. This is about creating space and stimulus for people to connect with the vision and how they can adapt to more effectively lead it.

Success means positive change for the entire LU network, from our leaders and internal stakeholders to our customers and external stakeholders. All aspects of the system will experience the benefit of more empowered and engaged leaders.

Within our leadership team, this is a mindset shift from being extremely good at reacting to an incident, to anticipating and preventing it from ever occurring. Currently, we do this well when there is a compelling event, as previously described for the Olympics and more recent events such as the Extinction Rebellion climate change protests in central London. Being diligent and forward-thinking, meant the worst-case scenarios did not happen. The challenge we've been embracing is how to do this all day, every day – without that significant stimulus.

What have you noticed about the impact of LCS?

Due to the safety-critical nature of the work and the command and control governance structures, this environment is highly structured, and this typically suppresses creativity. It's easy to find reasons not to do things or barriers to making even the smallest change. Despite this, I can see LCS is unlocking our leaders' passion and opening new ways of thinking about leading and engaging our people. LCS is demonstrating the power of igniting motivation internally, rather than relying on external factors. Although it is early days, we are already seeing leaders who are challenging the status quo by implementing local initiatives to build engagement; engaging their teams in understanding how the business works and building more collaborative relationships with internal and external stakeholders where 'silos' once existed. I'm excited by the opportunity to create something that has a lasting impact for our teams and the customers they serve every day. ■

"To maintain excellence on a day-to-day operation the whole system needs to feel connected to the organisation's vision."

London Underground

Case studies

Sounding out high speed

Arup's SoundLab makes it possible to hear a new railway before it gets built.[5] The SoundLab is an immersive sonic chamber which allows users to experience the aural atmosphere and output of a project. This facility grounds plans and designs – from airports to theme parks – in their local environments, facilitating customisation and iteration before construction.

The SoundLab has been used extensively for proposals on the High Speed Two (HS2) line, allowing people to experience 'in your area' demonstrations of what the new high-speed trains will sound like and the impact of noise reduction measures along the proposed route. Simulated train sounds were created using calibrated recordings of the latest 217 mph high-speed trains. These were adjusted to consider the expected speed and length of HS2 trains and combined with proposed noise mitigation measures. The recordings were overlaid with ambient sounds representative of large residential communities along the route. By end of 2018, an estimated 25,000 people had heard what HS2 will sound like in their communities.

Top
Arup SoundLab

Opposite right
Crowds at Guxangzhou Train Station, China

Right
Trenitalia trains in Milano Centrale Station, Italy

Get yourself a ticket home, automatically!

Chinese rail providers are forging ahead with the digital revolution, implementing technologies to help users better utilise the vast network when they need it most.

For example, during Chunyun (春運) the annual Chinese New Year migration, over 389 million train journeys are taken across the country. The scale of this holiday increase in demand has proved a logistical nightmare for many but has presented a problem that technology providers have ingeniously helped to solve. The Gaotie Guanjia app automatically monitors the availability of train tickets and makes purchases for the user based on their pre-set demands[6]. This app helps to ensure people get home for festivities and reduces ticket queues and unnecessary stress at train stations.

New Emirates-Trenitalia partnership a 'pivotal step' towards better plane-train travel

A new codeshare agreement between airline Emirates and Trenitalia, Italy's national operator, will allow customers to travel onwards to some of Italy's most picturesque locations using one ticket[7]. Italian regions will be connected to Emirates' global network, 'significantly boosting the Italian tourism industry' according to Hubert Frach, Emirates' Divisional Senior Vice-President of West Commercial Operations.

Each year Emirates flies more than 1.6 million passengers to and from its four Italian gateways: Bologna, Milan, Rome and Venice. Customers will be able to board Trenitalia trains without the need to exchange their boarding pass for a separate ticket. This is, potentially, a pivotal step towards a better integration of train and airplane travel, giving customers the option to buy a single solution for their train and flight journeys, and improving passenger flow at airports.

Encountering art on the journey

Andrew Mead
Chief Architect (ARBUK)
MTR Corporation Limited

Many transport agencies around the world have embraced integrating art into their stations, which have expanded to accommodate retail, hospitality and residential developments as complementary facilities to the core transit infrastructure. Art in stations is not a sign of extravagance; rather, it helps railways generate value on a city scale, mainly social, but indirectly also economic value. Art encourages people to use public transport, improves customer satisfaction scores and showcases the city's cultural talent and vibrancy.

In Hong Kong, MTR has been commissioning site-specific artworks for more than 20 years. MTR's first artworks were commissioned for stations on the Airport Express Line where large-scale artworks are strategically located throughout the stations to give a sense of orientation and identity. Since then, the collection has grown to more than 80 individual artworks, featuring a broad range of pictorial and sculptural works located throughout the network.

Art by MTR is the critical element in stations that creates a feeling of ownership and strengthens the bond with the community. The artworks themselves are created by local and international artists who express their talent in a wide variety of materials, themes and forms. Together, the collection reflects the spirit of Hong Kong.

The artworks appeal to the local community, which can be seen by how many people stop to take photos of them. For those who are more curious, MTR arranges guided tours to explain the process of creating and installing the artworks and to reveal some of the anecdotes behind the creation of each work.

Most of us spend a lot of time in transit. Often it is the daily commute, but also travelling to important events that are part of our life journeys. Encountering art that provides a moment to pause and reflect on those journeys is what 'Art in MTR' is all about.

Artwork featured in Sai Ying Pung Station, Hong Kong

The sound of rail

Kym Burgemeister
Acoustics, AV and Theatre Consultancy Lead
Arup Melbourne

Colin Cobbing
Director
Arup, London

Operational railways produce relatively high levels of noise and vibration which can impact on people and workplaces near the railway. Managing noise and vibration emissions is critical to developing better railways and reducing the impacts they can have on local communities, staff and passengers.

Hearing what's to come

Community engagement is important during the planning process to ensure that new infrastructure has a social licence. Providing an opportunity to experience what a new railway might sound like before it is built (for example, using Arup's SoundLab) is an innovative way to allow people to understand its future acoustic impact and to help manage their concerns. SoundLab also allows designers to better understand and convey the benefits that different noise mitigation strategies can provide.

Mitigating noise

Controlling noise from a railway requires careful consideration of impacts on the neighbouring community, passenger-experience and cost of construction and ongoing maintenance.

For example, resilient track systems used to control track impact loadings and reduce vibration emissions can result in higher airborne noise emissions, increasing the in-car noise levels for passengers. In recent cases, additional rail dampers have been used to control the in-car noise, at the expense of additional track maintenance.

High-speed railways, in particular, result in significant levels of aerodynamic noise which is generated by the air passing over the train at high velocity. The sweeping noses and aerodynamic cowlings used on high speed trains are designed to reduce the noise. However, existing corridor and vehicle envelope limitations on conventional railway networks mean that noise barriers, placed close to the track, are still likely to be required to manage noise. Along with their cost and maintenance disadvantages, noise barriers can also be visually intrusive and present landscape and drainage impacts.

For this reason, earthwork bunds are often used to shield the railway, especially in rural areas where they can be created from excess spoil from civil works. This technique also prevents the economic and environmental disadvantages of transporting and disposing of soil off-site.

The level of wheel and rail roughness is a key factor driving both noise and vibration emissions from the railway. Essential measures to control these emissions are careful maintenance of the track surface (using rail grinding or milling) and the wheels (lathing to remove out-of-roundness and defects such as flat spots), as well as ensuring accurate alignment control during construction.

If railway tunnels are near buildings, then a range of resilient track systems can be used to protect nearby residential and commercial receivers from groundborne noise impacts. These track systems range from simple resilient pads for simple applications to highly resilient floating slab track systems. The latter provide the highest levels of noise reduction but are much more costly and slower to construct.

Special care is required when selecting track fixings for railway bridges or viaduct structures because reducing the track stiffness to reduce structure radiated sound will result in increased airborne noise emissions from the wheel rail interface. Therefore, designers need to find an optimum track stiffness that balances the noise radiation contributions from both the direct airborne sound and structure radiated sound.

Taking a balanced view

Ultimately, engineering design to control noise and vibration from railways requires holistic thinking, with consideration of health and social benefits of the infrastructure, as well as the environmental impacts and costs of mitigation.

A broad understanding of railway engineering, and particularly, how noise and vibration mitigation design solutions interact with other complex parts of the railway system, is vital to achieving the best acoustic outcomes for railway passengers, staff and local communities alike.

Man-made sound barrier, Davenport, USA

Accessibility, safety and security should go hand-in-hand

Sagrada Família Metro Station, Barcelona

Mei-Yee Man Oram
Associate
Arup, London

Simon Brimble
Associate Director
Arup, London

Sean McDermott
Senior Designer
Arup, Newcastle

Around the world social, political and environmental factors are combining to increase the demand for rail travel. However, as rail capacity expands so do requirements around accessibility, safety and security. These factors have often been considered separately but there's a strong case for a much more joined-up approach.

Issues around accessibility, safety and security are compounded by ageing populations and a growing range of passenger requirements. These trends are not reflected in current codes and designs, which are based on assumed averages. A more responsive, holistic approach is urgently required that fully utilises best practice in wayfinding and security design.

The importance of wayfinding

Wayfinding is a significant factor in making travelling passengers feel more secure and confident across the railway network. It comes in many forms: physical and digital signage, digital and audible announcements, and human interaction with staff. It is critical to accessibility and should be available to all users whatever their individual needs. Blind, partially sighted, deaf or hard of hearing people are particularly important in this respect.

Careful thought also needs to be given to creating a comprehensive approach that leads passengers from start to finish in a consistent design language, across all media. Clarity is critical, so that information that is often complex is relayed in an easy-to-understand way, even if the user is not a native language speaker. Physical wayfinding also needs to be conspicuous and easy to use on the go, with signage systems that are engaging and complimentary to the station environment.

Advances in digital technology mean that passengers are now able to receive personal messages on the go. As these alerts become a standard expectation for travellers it's important that systems are future-proofed to accommodate further technological developments. It's also important that these messages enhance information within the station and don't contradict it. Effective systems coordination of all wayfinding data and information is therefore vital.

Security design

Security design plays an important part in enabling a seamless journey for passengers as they move through the station, and it should be included from the outset of the design process. In this way, a variety of solutions can be considered – such as appropriate space layout and the integration of smart technologies – without needing to modify the scope or retrofit solutions later in the design process (as is commonly the case). Ultimately, thinking about security early on will result in solutions that are smarter and more inclusive.

Historically, security for disabled people, or young families required segregation to allow separate procedures to take place, which can result in inconvenience for the passenger. New technology and different management processes can remove some of these barriers and increase comfort for different types of passenger. To achieve real benefits, infrastructure clients will need to steer technology providers and advocate change in regulatory guidance.

Clever architectural layout and design can also lead to outcomes that are beneficial. For example, a layout that makes movement intuitive within the station can also provide clear sight-lines, that enable better contact between staff and passengers. They can also enhance CCTV coverage and natural surveillance of spaces. This helps staff to monitor the station space (thus reducing antisocial behaviour) and increases the feeling of safety at all times, increasing the confidence of all stakeholders. Providing this sense of confidence will in turn help rail appeal to a wider group of users, delivering greater social and economic benefits.

Cityringen, Copenhagen

Chapter 2

Sustainable development

Unlocking the wider benefits or rail

Rapid urbanisation has led to the uneven growth of cities, resulting in areas with poor connectivity to essential services and facilities (schools and healthcare), and social exclusion. These negative impacts can be avoided or alleviated through integrated city planning that focuses urban development around multimodal transport nodes and extends urban rail networks to marginalised communities.

Railways connect communities and play a role in the delivery of Sustainable Development Goals (SDGs) related to social and economic equality, but too much of a focus on economic growth can lead to an unintentional increase in social inequality. As an area becomes more desirable, land and property prices rise. This can help fund rail schemes (see Financing and Funding chapter, p. 94) but at the same time, there needs to be careful consideration for the existing communities around transport hubs to ensure they are not losing out from the new developments (see ‘Rail (really) for the people’ p. 45).

On track to environmental sustainability

Rail is often recognised for its relatively low (carbon) emissions per passenger compared with road travel.[4] Rail networks carry 8% of the world’s motorised passenger movements and 7% of freight transport, whilst accounting for just 2% of total energy use in the transport sector. Indeed, if all services currently performed by railways were carried out by road vehicles, the world’s transport-related oil consumption would be 15% (or eight million barrels per day) higher and transport-related greenhouse gas (GHG) emissions would increase by 1.2 gigatonnes CO_2-equivalent on a life cycle assessment basis.[3] There are many initiatives to encourage a shift from both cars and planes to rail *(SDG 13: Climate action)*. If rail can be complemented by other sustainable modes of transport for the first/last mile (cycle, walking, electric vehicles), the chances increase for successful transition from car to mass transit.

Rail is already the most electrified mode of transport.[4] Further electrification of railways responds to *SDG 7: Affordable and clean energy*, but it is not necessarily going to deliver emission-free railways. A full electrification might also be prohibitively expensive, and electric traction from batteries as well as hydrogen fuel cell trains offer appealing alternatives. However, the role of rail in the transition to net-zero carbon emissions must be considered over its life cycle (see ‘What does truly emission-free rail look like?’ p. 38), in the context of the circular economy (see ‘Circular economy to the asset rescue?’ p. 46). There are safety considerations to be addressed too, especially in the case of underground and high-speed rail.

The aims of *SDG 15: Life on land* can be supported by railways through the responsible use of land and controlling the impact on natural habitats. Restorative work on land next to transport schemes can facilitate regeneration post-construction and avoid distorting food chains or modifying the mechanisms of natural resistance. ▶

At a glance

Striving for sustainable development
Ensuring assets are environmentally, economically and socially sustainable

Understanding vulnerabilities
Addressing the factors that impact resilience

Improving access through rail
Connecting more people to the jobs and services they need

Addressing inequality
Driving economic growth without displacing communities

Thinking circular
Applying circular economy principles across the rail sector

Supporting biodiversity
Using rail land assets to create richer natural habitats

Saving energy
Combining sustainability strategies and new fuels to create energy-efficient railways towards an emissions-free future

Opposite
Train passing through a tunnel in Schollenen Gorge, Germany

With careful planning and execution, such interventions can even increase biodiversity (see ‘How can rail support biodiversity?’ p. 44). Certainly, this requires challenging the traditional approach of ‘compensation for damage caused’. The goal must instead be no net loss of biodiversity and restoration, where feasible, of important ecological habitats.

Resources: choose and use with care

Railways provide people with opportunities to make choices as consumers in line with *SDG 12: Responsible consumption and production.* For example, by choosing mass transport over a private vehicle, it is possible to reduce the impact on air quality and help tackle congestion. On a larger scale, responsible production and consumption can be exercised through decisions about the design and operation of stations, trains and associated infrastructure. Shifting away from the traditional linear economy to the circular economy, whereby all non-hazardous waste materials are considered resources, will help to minimise the negative impact over the whole life cycle. Change in the mandated lifespan of some elements could also be considered.

Driver of change

Successful delivery of the SDGs requires integrated transport governance and, in many cases, cross-sectoral collaboration. This is expected to contribute to yet another goal: *SDG 17: Partnerships for the Goals.* There are many challenges – including in energy, material use and business models – that offer opportunities for creative innovation by manufacturers, SMEs, academics and public institutions. If they challenge the current status, they will respond to *SDG 9: Industry, innovation and infrastructure.* ■

Alstom’s Coradia iLint; the first passenger train powered by a hydrogen fuel cell

2%

of total energy use in the transport sector is accounted to rail

1.2 gigatonnes

increase in CO_2 if all rail transport was carried out by road vehicles

Case study

Railing for the Hydro Generation

Hydrogen engines have come to be seen as an immediate opportunity for large-scale transport power generation. Companies including Alstom and Eversholt in the UK, as well as ÖBB in Austria, have been testing hydrogen trains. They are looking to explore ways of cleaning up their services, by replacing polluting and increasingly dated diesel-powered trains over future decades.

The technology has received positive government attention in recent years, as policy makers look to get tough on sustainability in transport, including rail. Hydrogen-powered trains are considered preferable as they do not require the full electrification of the rail network (only 36% of which is currently electrified in the UK[30]), which would require massive infrastructure investment to extend. The adoption of hydrogen-powered trains requires careful analysis to determine what level of standardisation is needed across the rail network to ensure safety and compatibility.[42] The green credentials of the rail network will become an increasingly important factor in attracting people to swap from cars to mass transit in years to come.

Achieving sustainable development goals needs a total systems approach

Anna Squire
Australasia Rail Business Leader
Arup, Sydney

Sustainable development is about creating a balance between meeting the needs of a growing population and the health of our planet by embracing environmental sustainability, safety, inclusion and resilience. With this in mind, the United Nations' Sustainable Development Goals (SDGs) challenge us to think more broadly and adopt a holistic perspective.

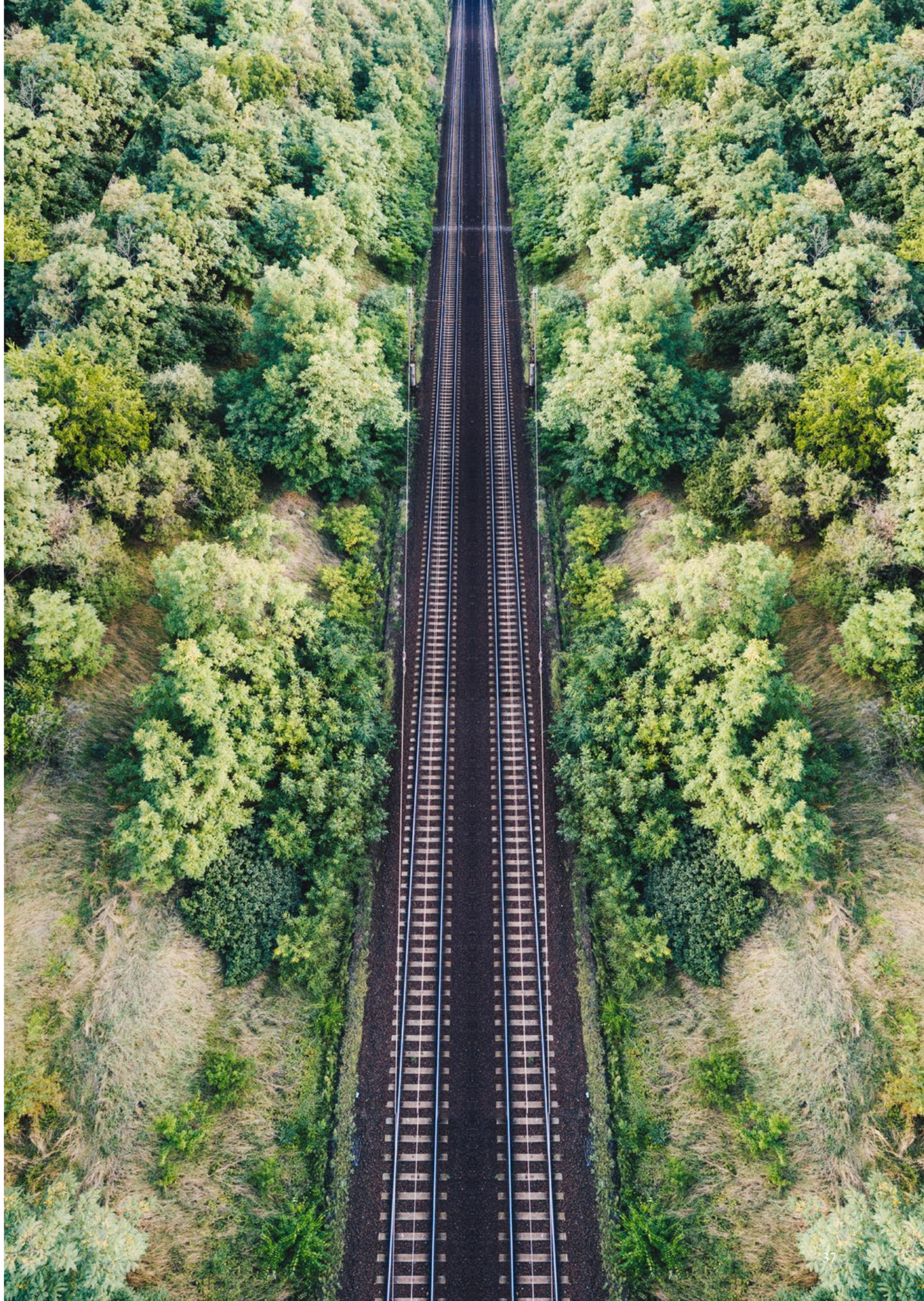
Rail, as part of a wider strategy for urban mobility, plays an important role in addressing many of the SDGs – some directly and some indirectly. Understanding this point requires a shift from thinking what rail 'is', to consider what it 'does'.

Rail underpins economic growth; it has the potential to support responsible consumption and a circular economy in the face of increasing urbanisation and population growth. It provides improved access to jobs, creating a more inclusive and equitable society. By connecting communities and providing improved access to education, rail also supports a more diverse, more skilled workforce, as well as cultural exchange, which is key to social cohesion.

Rail reduces road congestion and carries more customers and more freight using less energy than most other modes of transport. It also produces fewer emissions. The need to increase the use of renewable energy is supported by advances in alternative fuel sources for rail, such as hydrogen and solar power. Rolling stock energy efficiency is also addressed by technologies such as regenerative braking and heat exchangers. Railway stations such as the Fulton Center in New York (p. 40) are leading the way in terms of an energy-efficient and waste-minimising design approach.

Rail can drive better land planning if the balance with the potential impact on the surrounding environment is successfully considered. The creation of biodiverse rail verges is an example of how rail can help to support, rather than degrade, the surrounding natural habitat.

Overall, the challenges we face are complex and require collaboration within and between sectors, and interdisciplinary research that drives innovation. Rail is part of the solution to a sustainable future. In this context, a strong commitment of the rail industry's stakeholders to the SDGs will drive the development of safer, more resilient and sustainable railways, for everyone.



PV roof at Rotterdam Central Station, The Netherlands

What does truly emission-free rail look like?

Elizabeth Halsted
Associate Principal
Arup, Auckland

All forms of rail, from trams to metros to long distance services, are energy intensive. As the global ambitions for energy efficiency reshape the sector, the focus is going to be on how rail owners and operators can reduce emissions from services, operations and supporting infrastructure.

To be meaningful, emission-free rail means ensuring that the whole life cycle of the rail sector works on a zero-emission basis – from traction (trains and how they are powered), to property (stations and depots) to infrastructure (all other elements of the railway necessary for trains to operate). Without an appropriate whole system life cycle analysis, any developments or investment decisions will address only part of the problem.

I believe there are four critical components to delivering emission-free rail: leadership by governments and regulators; the right approach to technology, innovation and trials; finance and investment; and cross-industry collaboration. Let's look at them in turn.

Government leadership

With the state setting the agenda for public transport, a clear, consistent and predictable policy approach to emission-free rail by government, set at a national level, is critical to success. This includes a decarbonisation and emission target including clear dates for implementation and interim targets. A pathway to get there also needs to be identified, including metrics to measure success. This will mean working in partnership with the regulator to enable renewable energy and new technologies to be trialled and adopted to meet an emissions-free target. Incentives, policies and other government mechanisms to support innovation and trials will be important catalysts. High-profile government champions and communications campaigns will also be needed to support, communicate and deliver the government's vision and pathway.

Technology, innovation and trials

If a transition to an emissions-free future is to be a practical reality by 2050 a total-system approach needs to be taken across rail, energy, water, waste and communications infrastructure. Specifically, interdependencies and technology availability need to be identified and tested to allow the transition to happen successfully.

Rail is already the most electrified mode of transport. Beyond bi-mode (diesel and electric-powered) options, several technologies need to be trialled and tested that offer zero tailpipe emissions on non-electrified tracks. The most innovative of such technologies are battery electric trains and hydrogen fuel cell trains. Both electrification and hydrogen will play a complementary role.

Battery electric trains with small batteries can be used on partially electrified lines, enabling costs to be reduced by not electrifying those portions of track that present most difficulties (such as bridges and tunnels). Hydrogen fuel cell technology can complement this for services requiring long-distance movement of large trains with low frequency network utilisation, a common set of conditions in rail freight.

Finance

Making the financial case for emission-free rail is critical. Those aspects that can be implemented straight away, through existing franchises, residual value mechanisms and asset transfers, will need immediate focus. New mechanisms and innovation outside the existing franchising and procurement models will also need to be identified. Quick wins and transitional measures that could happen now include radically reducing the emissions footprint of infrastructure through materials procurement and manufacturing practices that reduce embodied energy and waste.

Across rail operations there are many ways to lower emissions by improving efficiencies, for example by using building management systems, and using efficient appliances and lighting. Likewise, the core rail service and traction can both be improved by reducing the weight of carriages, using electric or hydrogen traction drives, applying eco-driving principles, and introducing regenerative braking and occupancy-driven heating and cooling services. Finally, ancillary signalling and other trackside equipment that permits better utilisation of the rail network, will reduce the embodied emissions per passenger km or per tonne km.

Collaboration

Everyone has an interest in an emission-free rail network; it will lead to better air quality and is central to tackling climate change. Given the complexities of meeting the global target by 2050, we need to view the reduction of energy use in the network as a core, collaborative goal. We will then need to transition to zero emission energy sources as they become more available and workable. Reducing energy use means fewer emissions, and exerts essential pressure on good design and operating practices, rather than relying on low emission sources to compensate for wasteful behaviours.

In every part of the world, emissions is a systemic challenge; a paradigm shift that requires new thinking and major investment. To achieve genuinely emission-free rail, everyone will need to play a part. This includes government, the rail industry, energy companies, stakeholders and communities working together and holding each other accountable to a shared vision. If we do that, meaningful progress is a realistic prospect.

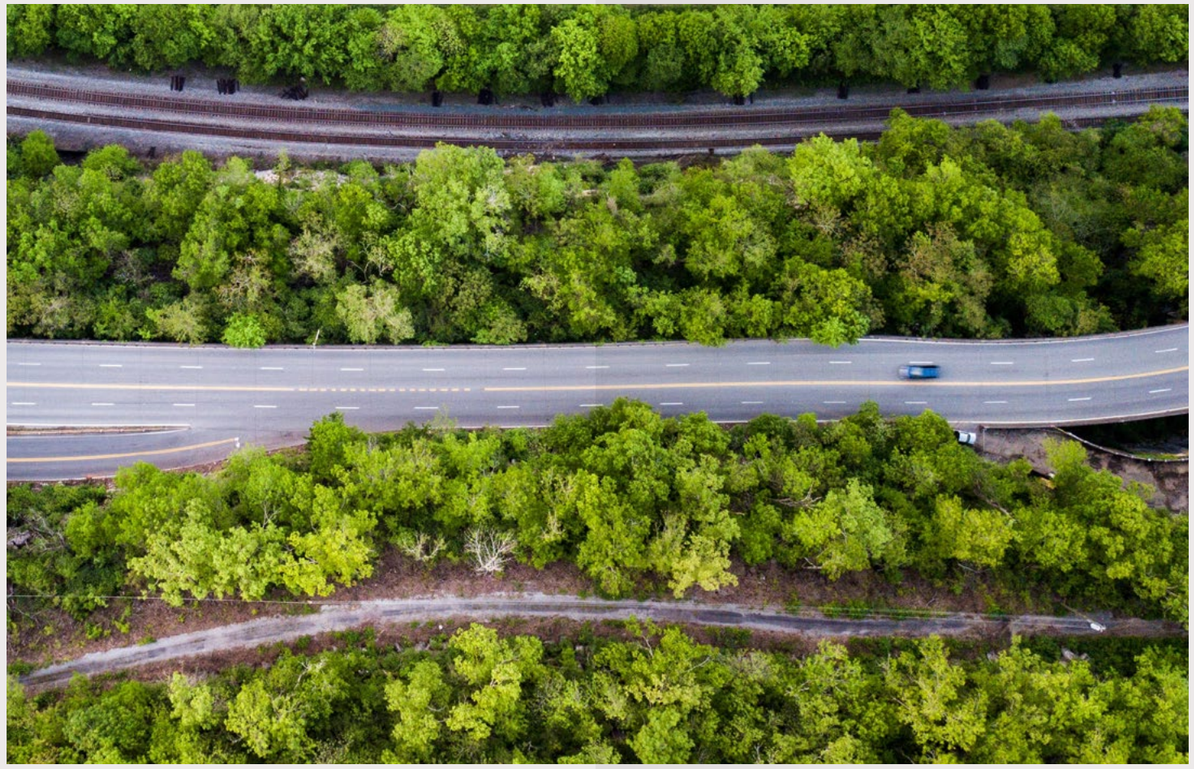
Case studies

The Fulton Center

The Fulton Center is a major portal into New York's subway system and an icon for six million subway passengers. The multi-use transit hub links 10 subway lines. Rooted in a long-overdue plan for operational improvements, the project led to an inspirational new public space that contributes to the revitalisation of Lower Manhattan by honouring the past while looking firmly to the future.

The sustainability and longevity of the Center, and its impact upon the community, remained key components in all design and construction elements throughout the project. From the outset, energy efficiency, life cycle value, pollution prevention and responsible waste management were priorities.

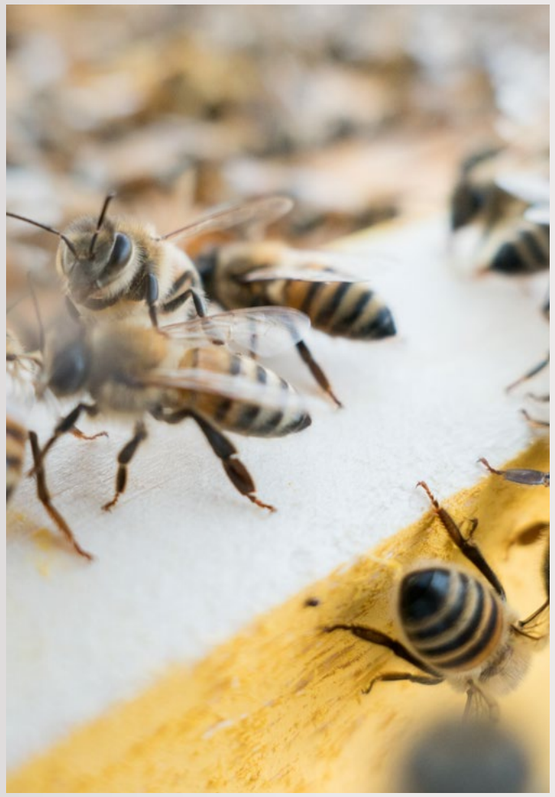
Daylight is maximised, energy usage reduced and more than 20% of materials used were sourced locally and made of recycled content. The building achieves more than 25% in energy savings compared to a building of similar type with half of the energy coming from renewable sources. Designed as a demonstration of an environmentally responsible 21st century rail transit centre, it achieved LEED (Leadership in Energy and Environmental Design) Silver Certification.



Top
The Fulton Centre, New York

Opposite right
Beehive installations on VIA Rail station rooftops

Right
Lookout Mountain, United States



VIA Rail gets buzzy

VIA Rail is installing beehives on its station rooftops in Vancouver, Winnipeg, Ottawa and Québec City in partnership with Alvéole[31], a company that combines beekeeping with education. Each station will have two hives hosting up to 100,000 bees, thereby promoting urban pollination and boosting local agriculture.

Besides pollination, there are also other tangible benefits: the combined output of these hives could be 800 pots of honey, 400 soap bars, 400 candles and 400 lip balms, which will be offered to charities. Commuters of all ages and backgrounds will benefit from education around bees and issues related to industrial agriculture, helping to raise awareness of the decline of bees and the consequential impact on the environment. It is hoped that the presence of bees will foster greater ecological awareness, putting everyone on the right track for protecting our environment, as well as populations of pollinators. Because bees forage flora within a 5-km radius of their hive, VIA Rail's bees will produce honey specific to the stations where they live, reflecting the ecosystems in each of the four Canadian municipalities.

On the tracks of ecology

A new and pioneering academic field has been born: railway ecology. Editors Borda-De-Água, Barrientos, Beja and Pereira have published a ground-breaking book, Railway Ecology[32], taking a comprehensive dive into the research available on the impacts of rail on the natural realm.

Their book considers compelling scientific analyses on wildlife mortality patterns, trends in biodiversity, and the barrier effect, as well as the means to mitigate the damage. The book advocates cross-fertilisation of techniques from road ecology into practice on railways. These include instituting wildlife crossings, introducing measures for noise reduction, warning wildlife of approaching trains and decreasing track vibration. All of these are easy wins in the effort to limit the impact of railways on natural environments.

Overall the aim is to inform best practice in a growing and vital field of human development, as railways spread throughout the world, connecting urban nodes in ever more extensive webs. Railway Ecology is a first step in aligning industry practice with ecological necessity, creating the opportunity for a brighter future.

In conversation

The energy-efficient railway

Experts in Japan, Taipei and America share their views on how an energy-conscious behaviour can be promoted in rail.

Masaki Ogata
Vice Chairman
East Japan Railway Company

B.C. Yen
President and Chairman
Taipei Rapid Transit Corporation

Cole Roberts
Americas Energy Leader
Arup San Francisco

How can we best promote the use of sustainable energy at the station?

BCY Several measures spring to mind. We have replaced fluorescent lights with LEDs at all the metro stations in Taipei. This saved 2.3 GWh of energy in one year on our Blue Line alone. We also thought about usage. We operate all our air-conditioning according to occupancy and not temperature, and have installed motion detectors on the escalators, so we don't waste energy when no one is using them. Thinking about the energy impacts of the materials we work with was also useful. All our cast resin transformers were replaced with transformers made from amorphous metal. Our data shows that core energy loss was reduced by about 70%.

MO At JR East we have implemented 10 eco-stations, with two more planned in 2020. The aim of these eco-stations is to produce our own energy and improve public awareness. We are proud to say that in 2018 we generated and self-consumed 2.15 GWh of solar and wind power at our stations and depots. We also set up mega solar power plants and large-scale wind power turbines that have generated approximately 18.4 GWh of electricity in 2018. In addition, we replaced 7,700 platform lights with LEDs in 2018, generating another 1.6 GWh of energy savings. Another positive action we took was the optimisation of the renewed underground ventilation and air conditioning systems within Tokyo and Ueno stations, which saved another 1.15 GWh of energy. We achieved this through data analysis via our Building Energy Management System.

We are now working on power storage systems and regenerative inverters. The inverters convert DC power generated by rolling stock into AC power for use across stations and assets like signalling equipment.

CR It might sound counterintuitive, but in my opinion the largest energy-saving opportunities come if you look beyond stations or depots. I am talking about planning policies that support appropriate development densities within walking and cycling distance of the rail network. This will allow people and goods to move to and from stations in the most energy-efficient way. Additional energy would also be saved through appropriately sized buildings that are constructed from materials with low embodied energy. These would incorporate sustainable systems for heating, air-conditioning and lighting.

In this scenario, stations could become sustainability hubs within communities, catalysing local area microgrids and heat networks that wouldn't be possible at lower densities. In total, these policies strengthen the business model and resilience of rail. Thus rail would not only contribute to a more sustainable society, but to stronger local communities too. The converse is also true. If land use around stations is poor, the result can be energy-inefficient sprawling development patterns. These can take generations to correct.

And what about on the train?

BCY We increased the use of regenerated energy in our power rails, saving 6.33 GWh a year on the Orange Line alone. As we did in the stations, we also fine-tuned the controls of the on-board air-conditioning systems, which are the second-largest energy consumer on trains. Now we adjust the car temperatures not only by season, but also depending on traffic hours.

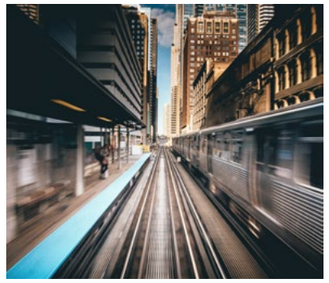
We are also extending the life cycle of our rolling stock by only replacing specific low-performing equipment, such as propulsion, air-conditioning or lighting systems. This has seen the introduction of higher performing systems like insulated-gate bipolar transistor (IGBT)-based propulsion and vortex air-conditioning. We've also committed to only using environmentally friendly refrigerant.

MO Since 2018, over 98% of our railcar fleet has been energy-efficient. New-generation railcars include features such as regenerative brakes and traction inverters with variable-voltage/variable-frequency systems. The Series E200 – the world's first diesel-powered, electric-motor-driven hybrid railcars – entered service on the Koumi Line in July 2007. This led to a decrease in fuel consumption of 10% and significant benefits in terms of reduced noise levels. These hybrid railcars have been introduced in several JR East lines.

All new rolling stock since 2013 has been equipped with LED lighting.

CR There are increasing opportunities to integrate renewable energy and energy storage infrastructure alongside rail alignments. For example, Arup's 2015 study for the Bay Area Rapid Transit (BART) authority identified opportunities for systems like solar photovoltaics and battery storage. The study showed that these systems could deliver between 10-34% of the energy used for train traction power and rail facilities – reducing costs, cutting emissions and enhancing resilience. ■

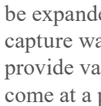
"It might sound counterintuitive, but [...] the largest energy-saving opportunities come if you look beyond stations and depots. I am talking about planning policies..."



Chicago, United States


The city of York, UK

How can rail support biodiversity?



Tom Gray
Senior Ecological Consultant
Arup, London

The potential to use rail schemes to minimise the impacts of climate change and improve ecological resilience remains untapped. Currently, the construction and operation of linear infrastructure is still associated with negative impacts that extend beyond the habitat loss within the construction footprint. These include: disruption or destruction of ecosystems and their function; the creation of a barrier to species movement; direct mortality of fauna (e.g. from train strike); ecosystem degradation through disturbance (noise, human activity); and permanent lighting impacting photosensitive species' movements and migration.

Although some impacts are unavoidable, new and upgraded railways can be designed to create valuable green corridors that help to restore ecosystem function (in line with the targets of *SDG 15: Life on land*) and provide net gains for biodiversity[33] – all of which ultimately benefits society.

The positioning of the railway route corridor within the wider landscape is important in achieving these targets. Each time a railway crosses a degraded river catchment, there is an opportunity to provide habitat restoration that will directly contribute to downstream flood resilience. The improvements can be expanded by creating temporary water storage to capture water for use during periods of drought and provide value to biodiversity. These interventions come at a price, but they reduce the need for costly infrastructure required to protect individual assets downstream. They also provide significant benefits to society as a whole, which must be acknowledged and accounted for at the start of a project.

The creation of biodiverse rail verges can provide long-standing habitat linkages between fragmented habitats that have been damaged by human activities such as urban and agricultural intensification. This facilitates fauna and flora movements, including microbes and invertebrates, and can improve ecological resilience on a landscape scale. Wildlife crossings above or below the route help to reduce the rail corridor's barrier effect and crossing points can be linked to other infrastructure associated with the railway. For instance, vegetated bridges facilitate safe crossing points, provided they are of sufficient size and habitat quality for the targeted species.

Rail schemes can positively impact the environment, without putting an additional strain on stretched budgets. The traditional approach – compensation for damage caused – needs to be challenged. We need to start recognising how restoring nature can help to create long-term resilience of the transport infrastructure. The railways of the future may actually result in reforestation, instead of deforestation. Early engagement with ecological experts will help to determine the most cost-effective and beneficial solutions.

Rail (really) for the people

Trent Lethco
Principal
Arup, New York

Within and between cities, rail increases transit accessibility of neighbourhoods, connecting residents to economic and social opportunities in line with *SDG 8: Decent work and economic growth*. Moreover, rail directly contributes to *SDG 11.2*, which focuses on providing access to safe, affordable, accessible and sustainable transport systems for all. This is particularly welcome in low-income areas, which have the highest need for growth and regeneration. However, the reality is not so straightforward. New transit makes an area more desirable, frequently leading to gentrification – raising land and property values and resulting in unaffordability. This often forces native communities to relocate and shifts the social composition of the neighbourhood. This, in turn, increases inequality and is in direct conflict with the aims of *SDG 10: Reduce inequality within and among countries*.

To avoid displacement, different measures can be put in place. Community land trusts or inclusionary zoning can be used to ensure affordable housing is available. The rights of existing tenants can be secured by just-cause eviction ordinances, homeownership protection policies, or right- to-stay measures, meaning developers are obliged to offer existing tenants new apartments at comparable rates to their existing housing. Existing businesses can be protected by imposing commercial zoning regulations, community benefits agreements, allocated arts and culture spaces, and lease-to-own programmes.

The effectiveness of these strategies depends on the degree of alignment with the stages of the scheme's development – especially the solutions involving the creation of protected zones, which should be considered early in the development, when it is still possible to implement changes to the proposed route.

Examples from around the world highlight successes but also some shortcomings in existing regulations. The New York City Inclusionary Housing Designated Areas Program granted developers an additional floor area bonus if they set aside 20% of units as affordable (below 80% of the area median income). Under Mayor Bloomberg's tenure, about 3,000 affordable units were created over seven years with the requirement that these units remain affordable in perpetuity.

However, the ambition of reducing inequality can also hamper chances of supplying decent work. The South African constitution and Bill of Rights obligate the state – but not private developers – to offer occupants decent housing when displaced by new development. Unfortunately, the obligation does not specify the type of shelter or proximity of new housing to the original residence, often resulting in social disruption, isolation from work and opportunities, and the severing of community ties.

Rail is a key element that positively contributes to socio-economic development, if the impact on equity is considered. The more broadly we think, the greater the opportunity for innovation.

In conversation

Circular economy to the asset rescue?

The ambition to move towards more responsible production and consumption is at the basis of the circular economy. Two Arup leaders discuss how implementing the circular economy approach can help asset management, one of the major challenges of the rail industry.

Carol Lemmens
Advisory Services
Global Leader
Arup Amsterdam

Andrew Went
UKIMEA Rail Business
Leader and Global High
Speed Rail Leader
Arup Manchester

What do we mean by circular economy?

CL Circular economy is restorative by design: it aims to keep products, components and materials at their highest utility and value, at all times. Our analysis of case studies around the world indicates that circular economy is still primarily implemented at the design stage, focusing on the use of recyclable, renewable or biodegradable materials. But this is just the first step: equally important are new business models and understanding how operations influence the health of assets.

To the rail industry, is the circular economy a potential headache?

AW The implementation of circular economy challenges us to modify our thinking (and to reconsider some of the regulations), but the concept is not totally new to the rail sector. Take the use of resources as an example. Rail structures are designed for longevity, which means that the selected materials need to be very durable; in many cases, once the assets reach the end of their life cycle, the materials can be recycled and reused (for example, rails are reused for sidings and areas where trains travel at slow speeds, or concrete sleepers might be cut in half for use on miniature railways).

We also see a gradual shift towards design for disassembly, especially in the case of new stations. Take the Cityringen stations in Copenhagen, which combine beautiful design with the practicality of a modular approach. The replacement of single elements becomes easier and more accessible, which may open avenues for the use of less durable, but bio-based or biodegradable materials, as long as they meet the safety standards.

CL Circular Economy is increasingly geared towards renewable energy options, e.g. for transport. Incineration of residual waste to obtain electricity – a practice that should be applied only after all possible other options for reuse and recycling have been explored – is an example of extracting value from resources that, in a usual linear economy model, would end up in landfill.

The potential of resource use and reuse is clearly huge. How do we unlock this potential?

CL For any system under consideration, a careful documentation of the composition and the provenance of materials is a prerequisite to subsequent upcycling, regeneration or reuse. This operation can be carried out using technologies like radio-frequency identification (RFID), while digital platforms can be used to store and access the data.

For the whole system to function, the information needs to be regularly updated; only this way will the conditions of an asset be transparent. The asset itself may then become the source of raw materials. We are keen to identify the potential for a second or even third life of a component, but to do so, we need to know about its deterioration over time.

Isn't this the same type of information that the rail industry requires to manage assets in a more efficient way?

AW Indeed, there are some similarities between the requirements for the successful implementation of a circular economy approach and efficient asset management, but I would be careful not to underestimate the challenge. I believe that digital technologies have enormous potential, but they need to be supported with a change in working practices. In both asset management and implementation of circular economy the availability of accurate data and a thorough understanding of the asset-operations relationship are essential. Ultimately, however, it is down to people: asset managers and asset operators need to commit to using these tools.

What about the historic assets where not all information is available?

CL This is a challenge that is recognised by many sectors; available data is often patchy and scattered. In some cases, we can use technology to evaluate the status quo and initiate regular data collection. Some of it will remain unknown and we will need to plan for this uncertainty. The key, however, is to make sure that the information out there is integrated and reaches the people who need it.

AW Creating accessible systems that enable us to store and access the information is a first step towards better asset management. The fact that it also aids implementation of circular economy is another argument in its favour. ■

"In both asset management and implementation of circular economy the availability of accurate data and a thorough understanding of the asset-operations relationship are essential."

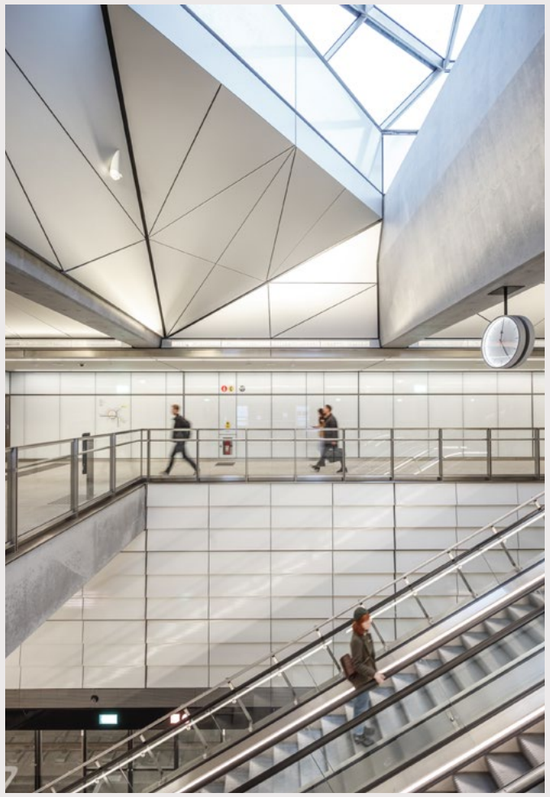
Rusting train carriages in Purwakarta Train Station, Indonesia

How Copenhagen sustains sustainable growth

Copenhagen's population is anticipated to grow by 30% to 755,000 people by 2040. In addition, the city is aiming to be the world's first carbon-neutral capital city by 2025, implementing the Copenhagen Climate Plan which addresses ambitious targets in energy consumption, energy production, mobility and city administration initiatives.

To accommodate population growth, the city is proposing to create a new sustainable district named Lynetteholmen, looking to utilise land reclaimed from the sea. Plans also include a metro which would be integrated with Copenhagen's existing metro –– through an extension of the Nordhavn Metro.

This vision for a new and sustainable district may also form part of the necessary climate protection for the city, which includes a breakwater to serve as storm surge protection. There are also plans to combine infrastructure expansion with green growth toward carbon neutrality, despite the 25-40% increase in passenger capacity forecasted by 2025.



Amtrak in North-East corridor

The United States' size and reliance on automobile and air transportation has stunted the adoption of high-speed rail in the USA. However, there are strong opportunities. Amtrak operates trains and infrastructure on routes in the US North-East corridor, primarily transporting passengers from Washington to New York and on to Boston. The area is densely populated and transit-rich, with growing customer group demographics, making high-speed rail a favourable option.

Amtrak aims to compete with airlines operating the same routes and will invest US$ 151 billion in high-speed rail up to 2040, halving journey times over the 400-mile journey. They have bought 28 high-speed Acela trains for use from 2021 and are investing billions into upgrading infrastructure. The travel time by train or by plane may become comparable, particularly if the commute to the airport, check-in and baggage collection, and arrival at the gate are all factored in. Additionally, the concentration of airports in the New York area results in congestion, and flights are often cancelled, deterring passengers from flying.

Top
Gammel Strand Station, Cityringen, Copenhagen

Opposite right
Amtrak Train Ventura California, US

Right
The proposed Cambridge Autonomous Metro (CAM)

Cambridge Metro

The highly productive economy of Cambridge in the UK is driven by skilled individuals, innovative start-ups, and is an increasingly attractive base for global corporations. Maintaining this success and allowing growth to continue sustainably requires a transformation of the transport network.

The proposed Cambridgeshire Autonomous Metro (CAM) provides one of the UK's most congested cities a solution to navigation through, and below, the medieval city centre. As a trackless, zero emission, flexible vehicle the CAM costs less than a typical metro or light rail scheme, but is able to grow to meet the future demands of the region. The aim is to alleviate congestion and enable development of jobs and homes, helping to fund the cost of the scheme. The scheme has been designed to harness the existing infrastructure, for example the Cambridge Guided Busways, while providing new infrastructure, maximising the potential benefits of East West Rail and other regional infrastructure investments.

Queenstown, Singapore

Chapter 3

Operational performance

Operating railways for everyone's benefit

A good rail system benefits all the stakeholders: passengers, operators, asset owners, staff, communities and businesses. Different groups may have different perceptions of benefit, but their interests are likely to centre on five topics; safety, reliability, cost-efficiency, value and sustainability. However, these factors are interdependent – intervention in one is likely to affect the whole system.

Rail is the safest mode of land transport, with less than one fatality per billion passenger-km,[11] and its throughput capacity is higher than most alternative urban transport modes. Indeed, metro rail can move 20,000 – 70,000 passengers per hour compared to 800 passengers per hour by car.[12] Despite this, the operational performance of rail must continue to improve in bringing the benefits of rail to the wider transport network.

Understand the challenge to enable innovation

To improve operational performance, the elements of the system and how they interact must be understood. This will come from a thorough analysis of people, processes, assets and/or external factors, with their functions and outputs. Doing so will enable the formulation of innovative, smart solutions that may not be the most obvious ones. For example, increasing the rolling stock may not be the best way of providing more capacity; reviewing timetables may be as effective and more cost-efficient.

Digital technologies can be used to monitor and evaluate parameters, to optimise controllable factors and to best manage factors that can be only loosely predicted, such as passengers. For example, sensors installed on assets and rolling stock continuously feed data, and increased processing power enables speedy processing of the information.[9]

New skills may be needed to translate the findings from the data into interventions in the system. The Asset Health Strategic Initiative in the US[10] is an example of an industry-wide collaboration using digital technology to improve safety. Railinc – an industry-owned information technology and services company – collects data from all Class I railroads and analyses them in collaboration with researchers at the Transportation Technology Center, Inc to inform modifications in maintenance practices.

The power of integration

Railways in Japan, Singapore or Hong Kong – systems with relatively few stakeholders – are often held up as exemplars that other countries strive to match (see 'Tales from around the world: Why do rail services differ so widely?' p. 60); but German rail companies have shown that it is possible to operate at high standards with numerous parties involved.[13] The key to success seems to lie in the formulation of a common vision that all stakeholders will support. Performance improvement requires everyone to know their role and understand how their actions affect others.

Integration and standardisation are all-important throughout the rail ▶

At a glance

Creating a common vision
Improving operational outcomes through shared stakeholder objectives

Providing real leadership
Attracting and empowering people with skills to drive positive change

Developing new skills
Enabling people and processes to make the most out the data, analytics and advanced technology

Integrating standards and systems
Adopting common platforms to generate greater asset value and to make multi-modal MaaS a practical reality

Balancing progress and performance
Weighing the benefits of new technology against the demands for consistent performance

Considering priorities
Recognising and managing trade-offs between investment and reliability

Maximising value
Enhancing whole life cycle performance through reliable, cost-efficient and sustainable assets

network and can maximise value for all stakeholders. For example, differences in track gauges alone can lead to increased journey time and cost expenditure for cross-border freight.[3] There are as many as seven predominant track gauges in use around the world – with major gauge breaks occurring in key freight transit locations, including China, Russia and Europe.[4] At each gauge break, cars must exchange their bogies for the different sized tracks, or alternatively goods are transferred from one train to another. Freight containers improve this operation but do not fully prevent the increase in time and cost.

Other important integration challenges include power systems (using alternative or direct current and voltage) and signalling conventions. Through collaboration, operators can guide interventions in operations and maintenance,[14] generate more value from fewer assets and reduce the total cost of ownership. Digitisation and automation certainly have a role to play in the move towards integrated railways (see ‘Blurring the lines of automation’ p. 58), but a thorough systems thinking is required to strike a balance between technology advancements and complexity (see ‘100% on time – is it really worth it?’ p. 68).

Complex, but not unmanageable

Digital technologies can be used to simplify and standardise the system, reduce costs and create new business models that are robust, reliable and cost-effective.[13] For example, moving away from separate transport modes towards Mobility as a Service (MaaS) requires the synchronisation of highly complex systems (see ‘The role or rail in the age of MaaS’ p. 92).

Additionally, challenges arising from unpredictable weather require the improvement of resilience strategies (see ‘A pathway to rail resilience’ p. 91).[1] Existing regulations may also need to be reviewed and other changes may be necessary throughout the rail ecosystem to ensure the right conditions exist for implementation. New skills will be called for and some roles may be redefined.[15] For example, shifting the business model from procuring a physical rolling stock fleet to securing available carriages will create stronger links between operators and original equipment manufacturers.[16,17] This will help to realise the benefits of condition-based maintenance (as well as predictive maintenance in the future).

Likewise, some remote inspection technologies do not have official approval to be used in the field, as the existing regulations lag behind technologies. In this case, innovation may still happen on a smaller scale, although it may take longer to see any benefits. Ultimately, there is a need for an industry-wide leadership that is able to lead and deliver change. ■

20,000–70,000

rail passengers per hour can travel via metro rail, compared to 800 by car

7

predominant track gauges in use around the world, with major gauge breaks causing time and money expenditures

“Technology, of course, is essential and has allowed us to make great improvements in rail systems safety, reliability and maintainability. But in the end, what truly makes rail systems reliable and effective is a committed work force comprising competent people who are well trained and are able to effectively implement and manage the various systems to achieve the required performance reliability and quality.”

Chua Chong Kheng
Deputy Chief Executive
Land Transport Authority (LTA) Singapore

Five lessons for better rail in a changing world

Masaki Ogata
Vice Chairman
East Japan Railway Company

The conductor
Tokyo, Japan

A rapidly changing socio-economic environment is placing major pressures on our industry. From managing the impacts of urbanisation and demographic change to the increasing pressures on economic performance, the challenges continue to mount. Our industry needs to be able to adapt and grow to ensure that public transport continues to satisfy the changing needs of a modern society, while remaining efficient and cost-effective. At JR East, we believe we are making great strides forward to evolve our railways at pace, adapting to the change that constantly takes place around us.

Here are some things we've learned along the way:

Vertical integration means people work more harmoniously

At JR East, vertical integration has proven to be a successful model for our business. We own the infrastructure, land, facilities, vehicles, train control systems, and we also operate and maintain the railway. The success of our vertical integration is supported by a model we have developed called the Management, Technology, Operation, Maintenance, Infrastructure (MTOMI) model. The MTOMI model acts as a framework that helps align and strengthen departmental relationships, values and discipline across our company and employees. The framework encourages collaboration across departments, such as infrastructure and operations, and helps ensure every team is working towards common goals focused on safety, stable operation, maintenance and customer service improvements.

Safety always comes first

The safety of our passengers and employees is our highest priority. We have set a target of 'zero accidents involving injuries or fatalities', therefore, this is an area of major investment. The majority of this investment goes into the safety facilities, but also into training. We believe our employees' endorsement of the safety target is essential to foster a culture of safety on our network.

In addition to safety, other priorities include: punctuality, comfort, high speed, short total trip time, high frequency, high capacity, mobility, accessibility, high efficiency and sustainable development. Each day, we carry 17.9 million passengers on our trains, making JR East the highest capacity service in the world. This places unprecedented pressure to meet our customers' high expectations and needs. The large volume inevitably changes the quality and the essence – and this is an important development area for the railway industry. At JR East, we firmly believe that high quality, excellent customer service must be delivered no matter how large the number of passengers.

Develop a long-term investment strategy

Rail is an extremely complex industry, requiring large investments and long construction timelines for any new infrastructure. This can represent a risk for private enterprises, where change happens at speed. To create a sustainable operational cycle, we must consider the revenue, costs and investment levels at the same time. For example, JR East is now accumulating a reserve fund of £2.5 billion for a large-scale refurbishment of the Shinkansen infrastructure, planned to be undertaken between 2031 and 2040. When it comes to a safe and reliable railway, a long-term view of the capital investment programme is essential.

Unlock digital's potential to improve operations

The development of information and communications technologies, artificial intelligence, Internet of Things, and big data can bring significant innovations to operation and maintenance. This offers us new insights, such as condition-based maintenance (CBM), where asset management becomes predictive and preventative. Another example – and a challenge we are currently trying to solve – is how to improve the automatic proposal system of the train/crew diagram during the complicated through-operation (i.e. the change of operators at a specified point on the line/service). As part of this, we aim to introduce AI to simulate the implicit knowledge and experiences of experts in the Operation Control Centre. A steady and agile, albeit challenging effort, will ensure our operation is robust and efficient in the long run. We will see even greater benefits achieved through advanced ICT in the future.

Collaboration and harmony determine success

For us, being able to create a harmonised balance between infrastructure and service has been enabled through close alignment and collaboration between operation, maintenance, management and technology – the four key elements of our MTOMI model mentioned above. It has led to many positive steps forward in our efforts to deliver operational excellence at JR East. Our challenge now is to improve and innovate our system through ICT so that we can continuously and positively move forward.

Blurring the lines of automation

Phillip Hudson
Associate
Arup, London

Fully automated Cityringen line, Copenhagen

The past 40 years have seen a proliferation of automated (self-driving) urban transit systems all over the world, from São Paulo to Singapore. But can existing technologies be used to regulate the train service and control overall performance, especially on bigger, faster intercity or regional rail networks? Will we ever see a fully automated nationwide rail network?

We have the technologies to deliver the train-driving element nationwide. On Eurostar, on the Shinkansen train in Japan and on both the Chinese and European Train Control Systems, conventional signals have been replaced with train-borne computers that communicate with a central system to calculate their required speed and braking curve. If the driver exceeds a designated speed, they brake automatically. If these trains could fully control their own speeds and check for obstructions on the track via automatic obstacle detection technology, how will the role of the driver change?

Our approach towards traffic management requires reconsideration too. Of the various levels of automation developed, traffic management systems tend to be used to assist human train controllers rather than to fully control the service. In the UK's traffic management programme, for example, the complexity of developing and integrating a traffic and signalling control system that can deal with numerous varieties of disruption has been challenging. Misconceptions about changes to the existing workforce and safety of an automated service are certainly not helping. These concerns do not seem to apply to China, however, which is leading the way by developing an artificial intelligence-based system of train control, reportedly using big data and deep learning to optimise train performance across an entire network alongside automated high-speed trains.

High speed, however, isn't the only impetus to digitalise. Many European cities, despite having extensive rail networks, suffer from low levels of service frequency. Schemes such as London's Thameslink and Crossrail programmes seek to unlock capacity by using metro-style, automated train operation and digitally aided signalling systems to increase frequency in core sections of their routes. Furthermore, the concept of metroisation (using existing heavy rail networks in cities to deliver metro-style service frequencies by utilising digital technologies) could be another solution to our urban transit challenge.

Regional trains that 'go digital' on entering our cities could be just around the corner. When they do arrive, they'll be competing with a new generation of self-driving cars and other autonomous vehicles (AVs). Will we even need the extra capacity that rail digitalisation will create? AVs carrying multiple passengers or even just autonomous 'car-shares' could compete on price and comfort, whilst adding the extra convenience of providing a bespoke journey destination.

There are two distinct advantages to the digital train revolution. Firstly, railway digitalisation will turbo-charge the speed advantage of a train service. Indeed, computer-controlled signalling and train driving systems can be planned and optimised in advance, and managers and operators of digitised infrastructure have much more control over train movement and conditions, potentially facilitating ultra-high-speed travel (the Shanghai Maglev can travel at 429 km/h, for example).

Self-driving cars, on the other hand, will be restricted by the road speed limit and by their own vehicular design limitations. Secondly, because the train service is planned by digital train planning and control systems, 'train jams' are minimised, while high passenger capacity is guaranteed. On the contrary, self-driving cars, even with the aid of live traffic data updates, will struggle to avoid our ever-more congested roads. In the future mobility context, trains and AVs could enhance each other by just doing what they do best: trains will comfortably move many people at a high speed through urban and intercity networks, and AVs will take them home safely via routes the train cannot reach.

In conversation

Tales from around the world: Why do rail services differ so widely?

Around the world rail service levels vary enormously. Why does such a discrepancy exist and what can we do about it? Can technology provide a solution to chronic rail sector issues?

John Fagan
Director
Arup, London

Oliver Bratton
Operations Director
European Business
MTR Corporation Ltd

Timothy Keller
Director of Rail/Transit
Operation
Integrated Strategic
Resources, LLC

The Japanese rail system is next-to-perfect and its praises are sung all over the world. Why not just replicate their system elsewhere?

OB Organisations with extremely high levels of reliability place equally high value on reputation and brand, and won't let incidents happen. They heavily invest in reliability and customer satisfaction but that's not the case everywhere. For example, in Hong Kong door reliability is exceptional because every door fault is managed with an investigation followed by a detailed plan on how to stop the same problem happening again. In the UK, investment is less focused on problem-solving, despite a similar maintenance regime. This makes the UK system more vulnerable to future failures.

JF I agree that the value of brand and reputation is important, and helps to create greater accountability. The geographical differences may be because in the UK, even on a single route, multiple organisations are responsible for overall performance. In places like Japan, while Japanese Railways Group consists of multiple regional rail companies, these companies manage all aspects of their allocated routes. It's challenging to create ownership of reliability issues in the UK, with different stakeholders pointing the finger rather than taking responsibility. But I also agree about investment. The Japanese are spending and focusing more on resilience.

TK Here in America, if you run 90-92% on time, everybody is okay with that. You don't want consistent delays, but perfection is not really something that's achievable with the current level of investment. We are investing heavily in new infrastructure, but the effects of this will only become visible in around 10 years, when it's complete and there is a history of operation. However, investment is the key. We live on very thin margins here – far too thin to increase our on-time performance to anywhere near Japanese standards.

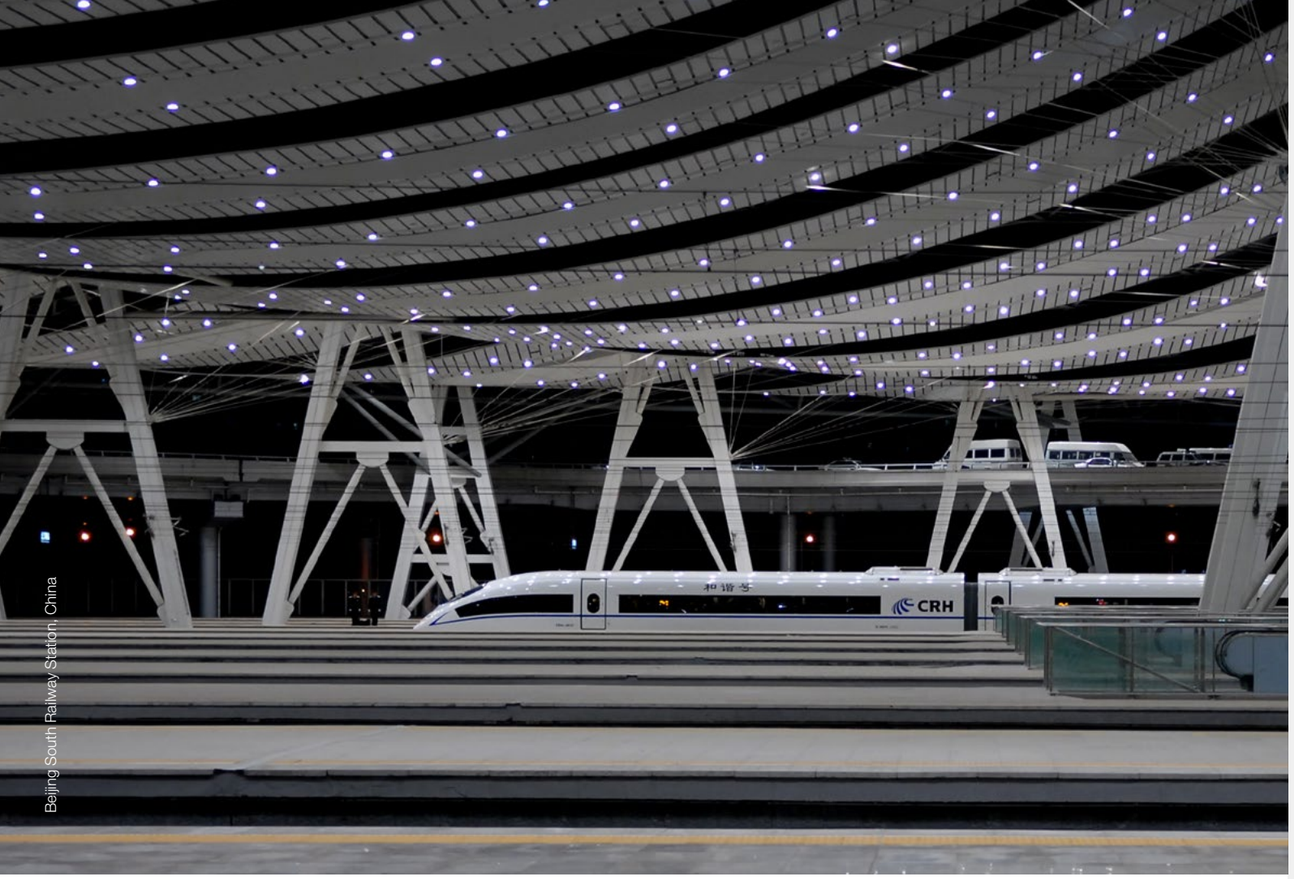
OB Also, in Japan and Hong Kong property development helps to fund the operations, increasing available investment. Moreover, the Japanese railway tends to operate on single routes, which helps to avoid complex junctions and facilitates scheduling. Here in the UK everybody tries to use the same congested infrastructure, which creates a high level of complexity.

JF Yes, to maximise capacity timetabling has become very complex in the UK as we squeeze more from the network. Our franchising process has nudged us in this direction by incentivising growth in passenger numbers. This has been delivered incrementally by running more and more services on congested parts of the network, making operational delivery challenging. There would be a real benefit in stepping back to consider how we can simplify timetables and strive for more standardisation. This would help us innovate and implement digital signalling technology more effectively, enabling trains to reliably run closer together, which would create more capacity for customers.

On the technology note, will it really be the solution to everything?

TK Here in New York City, technology is actually a significant problem. Every time we attempt to advance technologically, the complexity from an equipment perspective increases and it seems to slow us down. Suddenly, you rely on third parties for repairs, often at the software side. But then again, technology is only part of this. In truth, you could move the trains on time if there were no people. Once you put people into the system you begin to have incremental delay. You may think that by running fewer trains over a similar infrastructure, you could achieve a greater on-time performance; on the contrary, we're finding that if we onboard too many people to too few trains we run less efficiently.

OB I completely agree. It happened a few years ago in Hong Kong, where they improved the performance of the system by running more trains, which, as you say, may seem counter-intuitive. In the UK, there are ►



Beijing South Railway Station, China

so many other factors to consider, such as infrastructure reliability. We are still struggling to identify what the key problems that impair service reliability are. In terms of the data and technology, expectations are moving faster than reality. It is challenging to get new trains into service because of the technology on board. This said, when we do get real-time data and technology outputs, there will be lots of fantastic things we can do to improve the customer experience and our own processes. Think of maintenance or space planning. The challenge will be to keep pace with the arising business opportunities.

TK We face similar issues due to technology adoption, such as early obsolescence. Just when we roll out the technology, it becomes unsupportable. We have equipment that we expect to use for 25-35 years; instead, after ten years many components are obsolete, after 20 theparts are almost unobtainable. That's something that we're wrestling with.

I wonder if we should question the time span of our designs? Should we design for a 15-year lifespan, rather than for a 50-year span?

OB The problem is that if you're going to roll out a national signalling system, it will take 35-40 years. It takes time to roll out a major piece of national infrastructure across the whole country.

JF Indeed. The scale of the investments required to develop these technologies and roll them out on a national scale means that they need to be considered over a long term if they are to represent value for money. Making the business case for investments such as digital railway and European Train Control System signalling has been challenging in the UK. The end state is attractive; however, the scale of costs and limited benefits in the early stages mean that a longer-term strategic view is essential to getting things moving.

How can we improve this situation?

JF The industry needs people who can lead and deliver change and an industry-wide strategy that recognises the long-term benefits of technology improvements. This will enable leaders to work together to make the case for change more effectively and then implement it. Potentially, we will have to involve third parties for financing and funding and allow them to drive some of the quality into delivery. This will help us be more focused in terms of hitting timescales and getting things done.

OB One of the real challenges is balancing risk and innovation. In 2008, we introduced new rolling stock that was built on old operating systems. This choice minimised the bugs, but it meant it was prone to obsolescence. In the rail sector, we are building on software platforms that we are managing risk on. We want it old enough that we know the bugs, butnew enough that it is manageable and not obsolete: it is a really difficult balance.

Do you think this issue is being managed better in aviation?

OB I think so, but when you buy an airliner, you are spending much higher lump sums up front. That's not to say software systems on planes don't go wrong, as we know. The aviation industry is slightly more mature in this market than we are.

It is evident there are multiple challenges ahead. Do you think these will impact the perception of rail? Will you need to give up some market share to autonomous vehicles (AVs)?

JF Global trends, such as urbanisation, will place added stress on already straining systems and infrastructure. But denser urban areas provide opportunities for rail because it relies on density to function efficiently. When it comes to AVs, my feeling is that there is an opportunity and need for integration, so that AVs provide quick, easy and comfortable access to rail services.

OB I'm not sure that AVs can compete in densely populated areas: like cars they take up more physical space than a train. You would end up with gridlocked AVs instead of gridlocked cars.

On the note of global trends, let's talk climate change. How will unpredictable weather challenge our railways?

OB I don't think there's a simple relationship between weather and how we run train services. The challenge is that our risk appetite is dropping. We cannot control third-party trees falling on to the railway system. It partly comes down to the technology question: can we use technology better to help manage risk?

JF In the UK we will continue to have challenges with managing weather events, because of ageing infrastructure. Using technology more effectively to model the impact of weather offers the opportunity to provide better information so that we can plan how we manage the environment around our railway.

Despite the challenges ahead, do you think that the future for rail is bright?

TK I see the future as very bright. There are enormous opportunities so long as we provide the quick and efficient service people want.

JF Yes, I agree. The scale of success is dependent on the pace at which the railway can evolve and become truly customer-facing. But even without that, mass rapid transit's going to be an important feature for our urbanising society.

OB I agree, provided we can remain competitive.

JF Maybe these challenges are the type of wake-up call we need to push us towards more innovative approaches. ■

"There would be a real benefit in stepping back to consider how we can simplify timetables and strive for more standardisation. This would help us innovate and implement digital signalling technology more effectively, enabling trains to reliably run closer together."

Fleet requirements modelling for Transport for Victoria, Australia

Fleet requirements modelling forms the backbone of the business case for new regional trains in Victoria. This was used to assess the rolling stock required to meet Victoria's rail plan for the next 30 years.

Stabling requirements across the network were included in the model which informs the future master plan of Southern Cross Station, a major terminus in Melbourne. A network-wide model was developed from first principles to estimate a fleet size based on run times and service frequencies.
The model captures the profile of classic fleet retirement, and the restrictions of compatibility across the lines and fleet types. This was the first of its kind in Melbourne.

As well as enabling rapid testing of alternative future timetables and rolling stock allocation strategies, output from the model, such as kilometre travelled and maintenance window optimisation, aids an understanding of the operational efficiencies of new rolling stock.

Simulator of Human Operator Workload (SHOW)

The increase of automation in rail freight may have an impact on operator workload, but will it improve the operational performance? New technologies, if poorly designed and integrated, can contribute to errors, reducing system effectiveness.

Scientists at the Duke University in Durham, USA have developed Simulator of Human Operator Workload (SHOW),[18] a computational model to evaluate operational practices under various scenarios: with locomotive conductor only; with additional support from the train conductor; and with various levels of system automation.

The tool is available online and can be used to create a model of a custom system if input data, such as default tasks and times of task performance, is available. Incorporating factors such as shift time, traffic level and human and automation-assistance, the model can simulate over 2,360 trillion settings, a test scale not achievable in physical simulators with human volunteers. Based on the results obtained, a better human-machine integration can be achieved.

Top
Southern Cross Station
Victoria, Australia

Opposite right
Freight Train
Mauá de Serra, Brazil

Right
Facial recognition system
Guangzhou South Railway Station
Guangdong Province, China

Facing the future of financial transactions

In Shenzhen, advanced technologies backed by the ultra-fast 5G network are being tested by the local subway operator, including facial recognition ticketing. At Futian Station, instead of presenting a ticket or scanning a QR bar code, commuters can scan their faces on a tablet-sized screen mounted on the entrance gate;[19] the fare is then automatically deducted from their linked accounts. Currently on trial, the facial recognition ticketing service could help improve the efficiency of handling the five million rides per day on the city's subway network. The technology already works to identify users within three seconds, much faster than a manual ticketing system.

By introducing facial recognition to the public transit system, China has taken another step toward integrating this and other artificial intelligence-based technologies into everyday life. To use facial ticketing passengers are required to register their biometric facial information and link this to their payment accounts. Facial recognition payments, however, may be inconsistent with data and privacy protection regulations in other parts of the world.

Hyperspectral remote sensing on road and rail networks

Advances in remote sensing technologies provide opportunities to improve how road and rail network assets can be managed. In the first ever collaboration of this kind, Highways England and Network Rail are joining forces to investigate the advantages of using hyperspectral imaging, in combination with LiDAR and high-resolution aerial imagery, on both the road and rail networks.

Successful use of this technology will bring a better understanding of assets and their infrastructure risks. Specifically, more efficient and effective planning of maintenance and renewals will be enabled. Improvements in safety will result from reducing the need for people working on the rail networks, and higher network availability will follow the diminished closures for on-site inspections.

Remote sensing technologies have the potential to provide valuable information on asset condition over time, while reducing the need for people working on the rail networks. Ultimately this will enable better decision-making on maintenance and renewals.

Jakarta commuters

Set to become the world's largest city by 2030, Jakarta is already one of the most congested. As Indonesia's economic hub, Jakarta's infrastructure is stressed by the country's growth. With a daily mass movement of people, the city's rail system faces immense stresses and strains, due to passenger numbers that were not originally designed or planned for. This situation, combined with its ageing rolling stock, operational complexities, level crossings and infrastructure incompatibilities with modern transport, led rail operating company Kereta Api to invest in creating a better experience for passengers across its vast network.

The project started with a 200 kilometre-long, almost century-old section of the network, with six commuter lines servicing over one million commuters daily. Across this network operational improvements and investments are now underway to increase short, medium and long-term capacity and provide better reliability. This will help tackle congestion by re-shaping the city's rail network, and it will provide more attractive options and better connections for communities across Greater Jakarta.

> “Having experienced tremendous growth in railways in recent decades, China is still expanding its rail network to cater for rapid urbanisation. This continuous expansion creates challenges for the government, such as overcrowding of existing lines (particularly trains and stations in the city centre), funding burden for new lines concurrent with coming asset renewals and maintenance difficulties for iconic features. Of course, challenges come with opportunities. The current wave of interest in delivering sustainable future railways offers an opportunity to apply a total systems approach to planning, designing and operating our railways.
>
> We aim to get the most out of the whole life cycle of rail, while delivering an excellent experience for customers.”

Nelson Pong
Associate Director
Arup, Hong Kong

Stasiun Palmerah, Jakarta, Indonesia

100% on time — is it really worth it?

Stefan Sanders
Principal
Arup, Melbourne

“Commuters suffer London train delays as new timetable arrives.”

“The doors on one of Sydney’s new Metro driverless trains failed to open this afternoon, causing delays and huge queues, marring what the New South Wales Government hoped would be a day of celebration.”

These are some recent news headlines from across the world highlighting the public demand for excellent performance in rail and mass transit systems. Thanks to social media, frustrations caused by the delayed trains are surfacing and forcing railways to address their performance. But is 100% on-time performance realistic, or even reasonable?

Before we answer this question, we must realise that railways are a system, and they require holistic thinking. Various elements interact and contribute to the final outcome. Control systems and infrastructure, especially if managed digitally, can enhance capacity. In addition, high levels of rolling stock customisation add to the challenge by imposing complexity. Finally, there are operations – the plan or timetable, the railway employees, the leadership, processes and systems that enable a daily service. Though often forgotten, they are at the heart of delivering punctual and reliable performance.

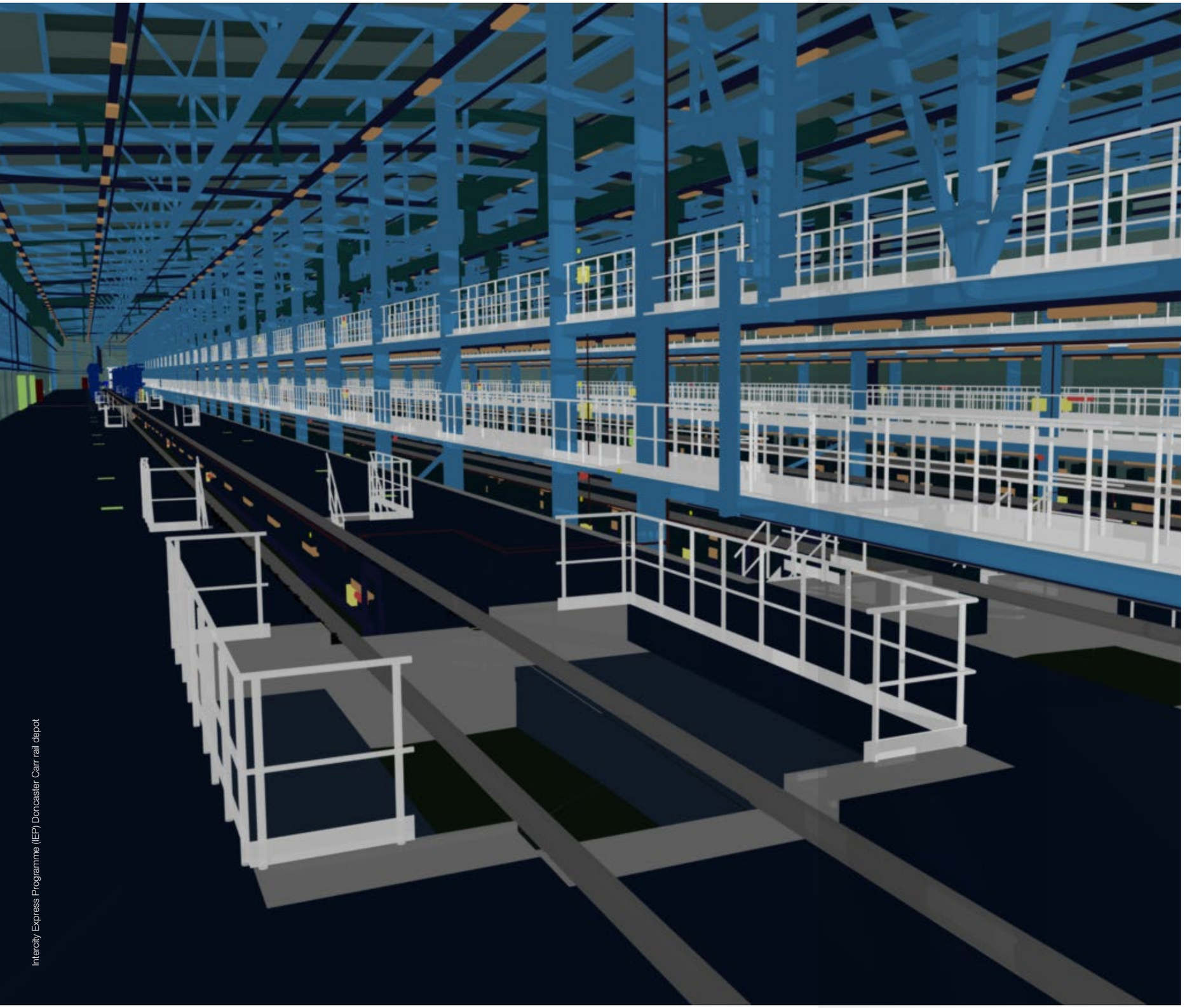
Investments in assets are needed, but the excellence cannot be achieved without clearly defined, well-organised operations and responsible people. Therefore, the culture around operations matters too. A work environment where performance is prioritised, managed and monitored, inevitably leads employees to focus on it. Conversely, employees will tend to neglect performance if they have no appropriate instruments to measure or manage it.

Like any system, railways are affected by stresses and shocks, which can happen at any time and arise from a signal, train or points failure, but also from unexpected weather events. In such cases, time is of the essence and plans, capacity and leadership are needed to recover quickly and prevent disruption from spreading. Thanks to digital technologies, incidents like this can be recorded in real time and this information used to improve the resilience of the system. It is important, however, to be able to estimate which is more likely to be effective: a change to asset (infrastructure, rolling stock) or the modification of operations?

Rising demand in the UK has stretched ‘dwell’ times at stations as trains have taken longer to load and unload, which in turn has affected performance. The solution came through operational intervention: for example, the London Underground deployed staff to help dispatch peak trains through passenger movement management, which improved performance significantly.

Coming back to the increasing passenger expectations, one could ask – for a system that is so complex – is it feasible to strive for perfection? Should 100% on-time performance be the goal? The answer, even if it may seem upsetting, is ‘no’, especially on longer journeys. The investment costs must be balanced with the resulting gains (revenue and passenger journey time savings). Inevitably, there comes a point where cost outweighs benefits and not every stress and shock can be managed. Higher risk items need to be prioritised.

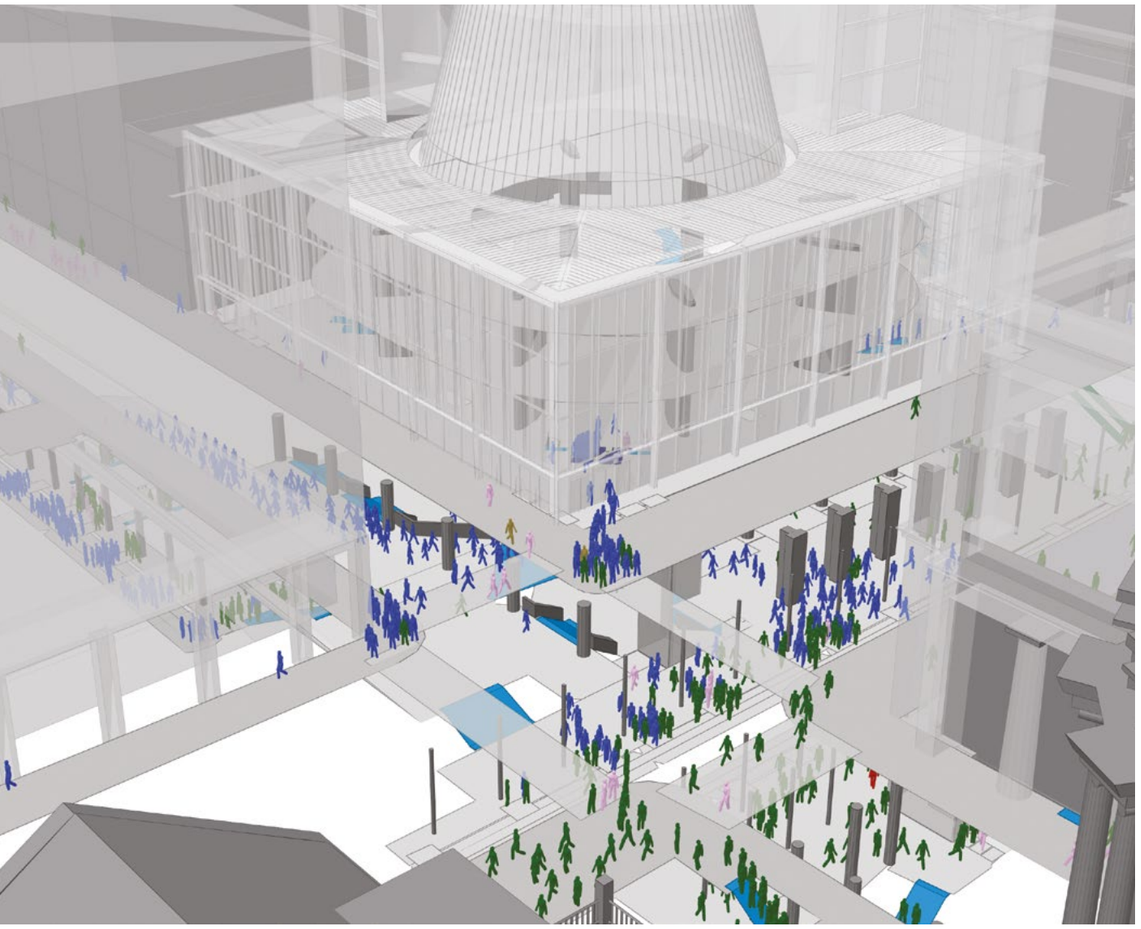
The best performing metros and railways in the world typically achieve 98-99% on-time performance, but not 100%. This, however, is not a call for mediocrity, but for careful consideration. In each case, we need to be able to define what reliable service means in terms of on-time performance and what level of investment is required. Allocating money for the most effective measures is essential, especially when budgets are constrained.



Intercity Express Programme (IEP) Doncaster Carr rail depot

Chapter 4

Digital evolution



Technology is only half the answer

Digital evolution equally affects assets, operations, people and organisations. Technology is only half the answer; the other half depends on the simultaneous actions of all stakeholders working towards a common vision.

Digitised assets: the next frontier of asset management

The rail industry has enormous digitalisation potential. Many technologies are already being implemented (albeit gradually) and examples of proof-of-concept are being brought into operation. Across China's urban rail network, most of the rolling stock is operating on at least Grade of Automation (GoA) 2,[20] and many GoA 4 lines have been completed in recent years. In March 2018, the opening of the Pujiang Line in Shanghai saw the global line length of GoA4 metros reach 1,000 kilometres. Since their introduction in the 1980s, fully automated metros represent 7% of the total length of installed metro assets today.[21]

However, intercity rail in China, especially high-speed, is further behind. Work on implementing automatic train operations (ATO) for intercity rail has been announced only recently by China Railway. Yet, there has been some progress: stand-alone driver advisory systems (S-DAS) already support a driving style that is energy-efficient and helps improve punctuality.

Further expansion is being researched and tested to shift to connected driver advisory systems (C-DAS). C-DAS is integrated with the traffic management system and is fed instructions in real time, which results in a better response to the current situation of the network. C-DAS is the ideal scenario, though it still presents challenges, especially where multiple train operators (running different rolling stock) are using the same infrastructure. Standardisation – of both assets and software – is essential to enable interoperability. Moreover, interoperability is the basis of an integrated and robust system that, in the near future, will need to rely on real-time data inputs across different transport system players.

Uninterrupted rail operations require regular inspection and maintenance of both the rolling stock and the infrastructure. The disruption caused by such activities can be minimised by predictive maintenance, enabled by Internet of Things (IoT), self-powering sensors and real-time data transmission and analysis. Enabled by digitalised assets and data, condition-based and predictive maintenance reduce cost by up to 25%, worth almost €17 billion globally per year.[17]

The use of drones, robotics and machine learning in remote inspections is also being explored.

All these digital technologies have the potential to enhance the passenger experience, even though their implementation happens 'behind the scenes'. Other more visible instances include contactless payments, gateless stations, real-time updates to the ▶

At a glance

Creating connections
Using smart technology to improve passenger interactions

Sensorising assets
Preventing problems through self-diagnosing sensor technology

Seeing is believing
Using virtual reality to improve performance and inform designs

Mirroring reality
Integrating all aspects of the railway life cycle in a live 'digital twin' environment

Integrating all the systems
Minimising programme risks through a single Systems Integration Authority

Building new partnerships
Enhancing outcomes with innovative, risk-sharing approaches and improved regulation

Increasing resilience
Putting new technology at the heart of a resilient railway

Opposite
MassMotion pedestrian simulation by Arup of Fulton Center Transit Station, New York

planned journey, MaaS services and wireless internet underground.

Evolution of asset operation

Digital technologies change the way assets are operated and managed (see ‘Asset management should not be a crime...’ p. 79). Connectivity, data gathering, data processing (possibly real-time) and communication underpin the digital railway. The success of such systems depends on the accuracy, quality and completeness of the data. Therefore, integration and data sharing between the main system constituents is essential. Rail can learn data sharing from the aviation sector (see ‘Real time stations: applying lessons from aviation’ p. 84).

Automation and autonomy can lead to increased reliability, capacity, resilience (see ‘Blurring the lines of automation’ p. 58) and energy savings (see Sustainable Development chapter, p. 30), with further improvements from condition-based maintenance and predictive maintenance. However, automation has its challenges. For example, on the track, who is responsible for the decisions taken by a computer? Should a person be allowed to override the system? And in a complex system where data is sourced from multiple channels, how can vulnerability to cyber-attacks be reduced? The standardisation of software across systems can help to mitigate risks, and all stakeholders should establish common criteria and strive for interoperability. Technology alone, however, will not suffice; much is still down to people.

Upskilling and reskilling

New technologies require new skills and new, sometimes unusual, partnerships. Core engineering skills need to be fused with an understanding of digital capabilities and the basic rules of data analytics. The rail industry now needs more of the people who traditionally would have worked for tech giants in the services sector.

Systems thinking will become indispensable in the transition towards seamless mobility. However, for automation to be perceived as an opportunity rather than a threat, staff need to be at the centre of all communication and education activities in the transition. Good people management and leadership are as important as the ability to translate big data findings into engineering interventions. New professional capabilities will become mainstream, such as Systems Integration (SI) Authorities (see ‘The case for Systems Integration’ p. 86). The rail sector can learn from other sectors such as automotive, water or energy, which are already at advanced stages of the digital evolution journey. Although the challenges are not the same, sharing experiences across industries is beneficial. ■

25%

cost reduction by using condition-based and predictive maintenance

1,000 km

total length of GoA 4 metros worldwide in 2018

Shibuya, Japan

Case study

Rail specific insurance to mitigate cyber threats

Advances in information technology and interconnectivity have improved efficiency in transportation infrastructure, but they have also increased risks associated with cyber systems. As railways become increasingly dependent on digital technologies, they need to be protected by ensuring that robust cyber security is in place.

A German-based insurance broker for rail has created an innovative insurance policy to address the growing threat of cybersecurity attacks on rail companies.[22] Policy holders will be eligible for discounts from the specialist insurance provider based on their ‘Rail Cyber Index’ rating. The policy is designed to cover financial losses caused by railway-related cyber risks, such as network disruption caused by hackers accessing operational functions. It also covers conventional cyber risks such as loss of customer data, IT system breakdowns or cyber extortion. The package increases certainty for rail operators and investors, increasing the security and reliability of their assets.

Digital railways: why are we still waiting?

Dr Will Cavendish
Global Digital Services Leader
Arup, London

Across many areas of our economy and society, digital technologies are changing the way whole sectors work, and data is revealing new and deeper insights into everything from planning, design and operations to meeting net zero carbon reduction goals.

But for industries with long-established infrastructure and traditional ways of working, finding the right ways to both apply digital technologies, and use them to deliver real benefit, isn't necessarily easy. Rail is a sector that is both highly aware of the transformative potential of digital technology, but not always ready to take best advantage from it.

There are pockets of innovation that point the way forward though, and examples of successful digitisation in railways are growing in number. Network Rail in the UK is digitising its legacy infrastructure using sensors, big data and artificial intelligence to realise the potential of remote condition monitoring to radically improve its asset maintenance. Agent-based-modelling promises to greatly improve our understanding of user behaviour, reshaping future decisions about rail and transport systems. Or you could look at the State Railway of Thailand's embrace of a combination of blockchain and Internet of Things for signalling and goods delivery. Digital rail's potential is clear, even if adoption isn't yet ubiquitous.

Why, then, aren't railways fully digitalised yet? What are the missing ingredients of the railway of the future? Two things stand out.

Mobilising the scale of investment required

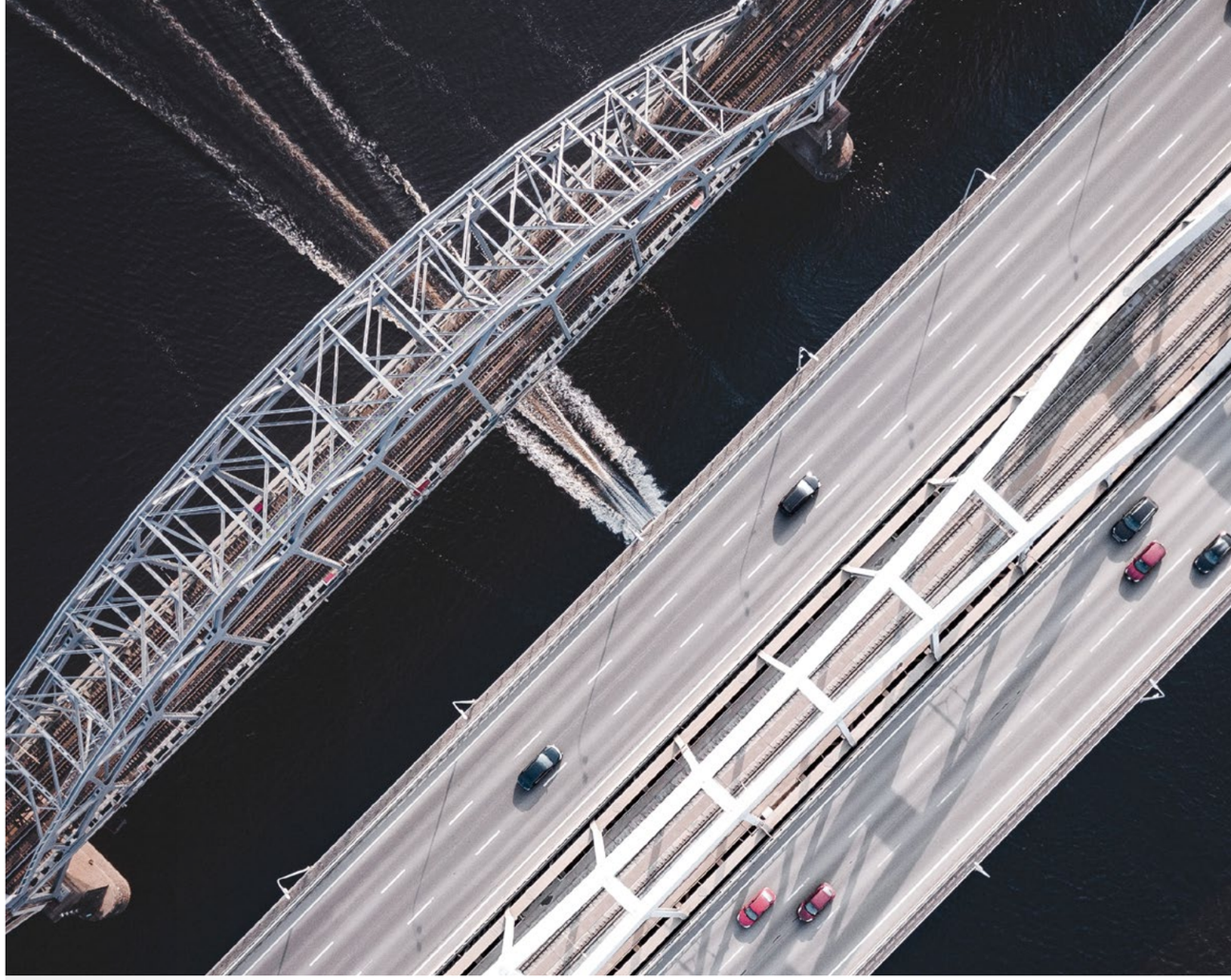
The first is resources. Successful implementation of the digital solutions that are now possible across all aspects of our railways will need sustained, significant, and network-wide spend. We need to ensure that systematic resources are allocated to digitisation, at far higher levels than currently. This is likely to require shifting from traditional contracting and supply-chain management methods, towards more innovative, investment and risk sharing approaches, almost certainly with the major technology firms as new partners in the railways. Everyone knows this investment must be made, and will ultimately drive service improvement and cost efficiencies. It's time for boldness.

The need for system-wide leadership

The second issue is system-wide coordination and leadership. Successful digital transformation of the railways will require, for example, common and shared data and technology systems. That means shifting from disparate systems and information to interoperable data standards; common technology codes; defined and shared approaches to cybersecurity; a system-wide modernisation of regulations, and more. Plainly, this cannot be done by individual operators or supply chain partners on their own. Rather this can only be achieved by enlightened, persistent and patient leadership by system leaders, whether they are governments or national rail agencies; and an investment in greater digital capability within those organisations themselves. Is such leadership currently being offered? Does it look like it is on the cards? Again, greater boldness is needed.

Artificial intelligence and smart infrastructure: learning from other industries

Rail can and should also learn from other industries, which are already using digital technologies such as artificial intelligence, machine learning and sensor-derived data to design and manage assets better.



In Beijing and Hong Kong, for example, Arup is trialling Neuron, one of the world's first AI and data-driven smart building systems, to improve asset performance, save energy and cut carbon emissions. In both the UK and other parts of the world, we have implemented sensor and IoT technology for smart bridges. This 'digital twin' technology offers valuable new dimensions to rail asset management, operations and maintenance. Operators will be able to quickly review real-time asset performance, diagnose problems remotely and test proposed fixes before having to apply them to physical components. For an asset-dependent industry, it's the start of an exciting new era.

Transforming construction and meeting sustainability goals

Digital also has the potential to improve the considerable amount of physical construction, manufacture and refurbishment railway operators must undertake. For example, employing robotic fabrication for fleet production or digital fabrication to quickly replace spare parts that can normally take months to replace, could save time and money for operators, while at the same time help meet sustainability goals. And we are already seeing these technologies mature into commercial propositions in other sectors. For rail, the adoption of these technologies is ultimately inevitable, so it's time for leaders to commit to and invest in the truly transformative (and transformed) rail we all know is coming.

A digital railway for everyone's benefit

Daniel Weiss
Associate
Arup, New York

Rail and transit owners and operators across the world are constantly striving to make service improvements. These include: meeting on-time performance metrics, maintaining a nimble security approach, preparing for extreme weather events, strengthening timely maintenance practices and delivering capital programmes. Achieving all these aims requires an engaged team, strategically employing best-in-class tools.

The rail sector has often been slow in implementing new technology to address these challenges, at a high cost to stakeholders. The solutions available today are game changers, and it is no longer tenable to ignore the opportunities and continue running business as usual. Embracing a truly digital railway will allow owners and operators to generate tangible operational benefits that will improve performance across all the challenges they are facing.

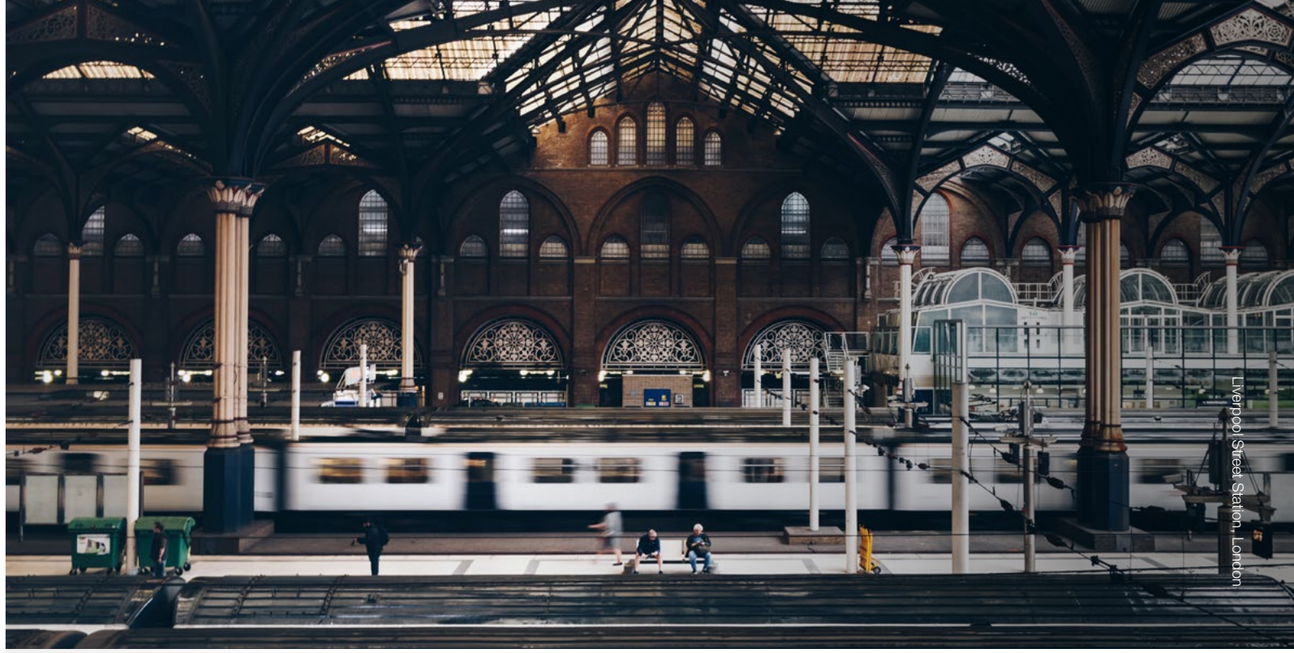
At a time when capital funding can be scarce, the digitalisation of railway signalling and controls is essential to increasing capacity and operating existing networks more efficiently. This, in turn, improves service frequency and on-time performance, reducing the knock-on effects of service disruptions. It also allows customers and transport network partners to receive real-time service information.

The digital retrofitting of infrastructure allows for remote diagnostics and for real-time field data to be sent to headquarters to inform decision-making. Equipping stations and the right-of-way areas around them (such as highways and footpaths) with beacons will help travellers navigate more easily – whatever their needs. It will also promote safer working in the right-of-way areas and improve incident response by railroad employees.

Developing a 'digital twin' of the systems infrastructure (an accessible 3D model of railway infrastructure configuration, with bespoke sensors to capture real-time status) will enable employees to make sound decisions during normal, emergency and maintenance operations. It will also help to expand reconstruction programmes by making the best use of limited resources and constrained work windows.

The range of infrastructure and systems assets used by different stakeholders are diverse, as are their needs. The commonality is that rail and transit owners and operators need to continually push the marketplace to develop safe solutions that will free up resources that can then be refocused to deliver on critical priorities.

Remaining open to effective change and continually seeking better ways of working and collaborating will be key to the transition to digital railways.



Liverpool Street Station, London

Asset management should not be a crime…

Anni Feng
Senior Consultant
Arup, London

Designing a station upgrade project sometimes requires unexpected skills. When seeking as-built information from the infrastructure owners, designers must often turn into detectives. First is the 'crime scene' inspection, evidence gathering and… interrogations. There are numerous witnesses, conflicting statements and even experiments.

This sounds as though it could be fun, but it is not, neither for the design team, nor the infrastructure owners, who are confronted with the fact that the assets are being operated 'blind'. Such 'black box' situations are currently handled by requesting contractors for each project to obtain accurate site information – as a result, multiple surveys are carried out creating multiple sources of truth. These surveys also represent additional costs to the infrastructure owners.

The increasing adoption of digital technologies calls for a change of mindset towards collaboration and openness.

Tools such as 3D LiDAR scanning and building information modelling facilitate the creation of a common platform for system operators and maintainers to input asset information and workflows, creating an integrated source of truth. Data for the digital models can be input in real time automatically via integration between systems and an internet of sensors. Careful curation of the digital models, such as ensuring data quality and privacy via blockchain, enables their reuse in the next engineering project.

With machine learning, different system failure scenarios can be predicted and mitigated. Infrastructure owners and operators must also view assets as interoperable eco-systems; this systems-thinking will enable the stakeholders to truly evaluate the impact of implementing digital solutions on the assets, processes and performance.

There is even more that can be achieved; if the integration is industry-wide, information from different locations can be gathered to improve decision-making and inform best practice.

Everyone has a role to play in championing collaboration across the rail industry, and in shaping the cultural shift of embracing digital technologies and transparency. Individual priorities will be very different. From optimising asset value via analysing network-wide condition data, to protecting digital and physical assets, through standardising procedures and incentivising innovation. However, the vision that inspires all of us in this industry may well be the same: providing an enjoyable and safe journey for everyone, every time.

Creating a train station in virtual reality

Elizabeth line train operator MTR Crossrail is using virtual reality (VR) to enhance its training programme. They have introduced a platform simulator allowing new employees to test their skills in a computer-generated train station.[23] Built in conjunction with Invirt Reality and using the HTC Vive VR system, the platform allows staff to walk around and interact with objects using movements and arm gestures. Training is staged across various scenarios, from reporting faults on critical station equipment, to dealing with safety hazards that are too dangerous to replicate in real life.

VR has already been deployed elsewhere in the rail industry, including aspects of Crossrail construction. MTR Crossrail finance director Andy King says that the application of VR to station staff training is a leading step for the UK's rail sector, and one that other operators might look to utilise in the future.[41]

Top
Elizabeth line using VR to enhance training programme

Opposite right
Wessex Waterloo interchange, London

Right
Cutting rail at Kings Norton Junction, Birmingham

The UK Wessex route

The UK Wessex route has a capital and maintenance spend of approximately £2billion within the current control period and includes the busiest terminal station (Waterloo) and interchange station (Clapham Junction) in the UK. In this context, keeping the railway running while achieving the planned portfolio of work is especially challenging.

The creation of a web-based dashboard called the 'Workbank App' provided the Wessex route with a single source of data on all capital infrastructure interventions. This gave the opportunity to remove unnecessary scope duplication while integrating and coordinating interfacing packages of works. This was in order to realise efficiency and prevent cost escalation through earlier identification and management of project interfaces.

As well as providing visibility of all planned works, the Workbank App increased reporting capabilities at project, programme and portfolio level. The app was the first of its type in Network Rail and has captured the imagination of the route, with hundreds of users interacting with the site within weeks of its launch.

Detecting issues earlier

For rail networks that are used intensively, the cost of track maintenance can reach almost half of the total annual budget.[25] Exposing flaws earlier would reduce costs. However, current methods of monitoring only find defects at later stages, when faults may require more radical interventions.

Scientists from Delft University of Technology in the Netherlands assessed rail failure risk based on information on visual crack length and crack growth.[26] Track images collected by cameras on the train were analysed using deep convolutional neural network (DCNN) to detect the occurrence and severity of squats. Subsequently, ultrasonic measurements were used to derive the general characteristic of crack growth as a function of million gross tons (MGT). This allowed engineers to calculate failure risk probabilities through an innovative integrated framework that has the potential to significantly reduce the operation costs induced by track defects repairs, reducing the overall risk of derailment.

Offering Rail Better Information Services (ORBIS)

A problem for any organisation with remote or field-based staff is ensuring that they have suitable access to the data and information needed to do their jobs. They also need the capability to easily provide data on work undertaken. In an increasingly digital world, data is critical to improve capacity, performance and customer experience.

Intelligent infrastructure in the rail industry allows for real time performance updates and predictive maintenance, resulting in cost savings and efficiency. A prime example is Network Rail's ORBIS Programme,[24] a seven-year, £330m award-winning business transformation programme. ORBIS provides for better asset information, and implementation of digital asset management solutions across the organisation. The programme helped Network Rail manage its assets more efficiently, cost-effectively and safely. It was also a first step towards real-time railways in the UK.

3D printing of parts

Additive manufacturing, sometimes referred to as 3D printing, could be used in the production of locomotive components, removing the need for castings and mould production. Instead prototyping, using rapidly produced moulds can be done in a matter of days – a huge gain in lead times for component design. The resulting components can also be more compact and precisely designed to meet the end-use requirement.

Another major potential gain is the ability to complete complex components in a single pass. For example, the potential areas of failure in an engine heat exchanger with a large number of sub-components, joints or welds, could be eliminated by additive manufacturing. Customers could place orders for customised parts online, these are then 3D printed on demand and delivered. Operators would be able to produce low-run parts as required, without needing the mass production of large quantities.

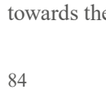
> “The transport sector is the fourth-most targeted sector by cyber attacks, after government defence, finance and energy. Eliminating the risks, be it data leakage or public safety, is impossible. However, by conducting thorough and holistic risk assessments we can focus on the vulnerabilities in order to reduce the risks.”

Takahiro Kishimoto
Senior Manager
Arup, Tokyo

Digital maintenance on Network Rail

Beijing Daxing International Airport, China

Real time stations: applying lessons from aviation



Alan Newbold
Director
Arup, London

The quality of rail services varies significantly around the world. What is common, though, is the call for continual improvement. The pressure to perform is rising and competition from other means of transport intensifying. However, these concerns are not unique to rail; in the search for new solutions the aviation sector may provide some interesting ideas.

Digital technologies offer great potential to address many challenges, provided they are rolled out properly. One critical factor that can deliver multiple benefits to operational decision-making (and directly affect the performance) is being able to share a single source of the truth across the sector. The introduction of such an approach in the aviation industry relating to aircraft turnaround has led to significant improvements.

Historically, the aircraft turnaround process was (and in many places still is) inefficient, adding to the pressure on the already congested runway, taxiways and stands. To resolve this, an initiative called Airport Collaborative Decision-making (A-CDM) was developed. A-CDM shared data across the airport business processes for the benefit of passengers, airport operators, airlines and all other third parties associated with the aviation process. This was one of the first initiatives that provided a single version of the truth to the airport system and started the journey towards the ‘real-time airport’.

Critical to these developments was the sharing of data. Without sector-wide collaboration, it would have not been possible to achieve the level of operational efficiency or the level of service expected by the passengers. Coordination by the intergovernmental European Organisation for the Safety of Air Navigation (Eurocontrol) and introduction of a common, standardised traffic management system were central to the success of a single source of truth creation.

A-CDM was a voluntary process that has now been adopted by 28 European airports, resulting in a significantly more efficient use of airport assets. It also positively affected the performance of the ground handlers and airlines.

The experience from aviation provides a proof of concept. It is worth considering how these best practices can be transferred into the rail sector. There are, of course, differences; the level of fragmentation is much higher in rail, for example. This fragmentation is not likely to pose a challenge in terms of digital capability, but it does create an absence of a common vision which may hinder successful integration.

Is ‘digital’ flattering to deceive?

Giles Pettit
Associate
Arup, Nottingham

Thirty years ago, the first computers were used on trains. Since then, onboard control has evolved to the point where trains are almost completely ‘fly-by-wire’. This means that all functions and train operator commands – from traction and braking to door control and sanding – pass through a centralised train control system.

Astoundingly, we also recently celebrated the 50-year anniversary of automated driving systems being introduced on the Victoria line of London Underground. Unlike the proliferation of train control, automation has subsequently been restricted to metro and light-rail operations. China, however, is leading the drive to deliver the first automated trains for high-speed lines, with trains able to reach speeds of up to 350km/h.

The ‘digital railway’ is full of promise, but no more than a handful of new signalling and traffic management schemes are actually being implemented. None of which are really experienced directly by the passengers.

So, is ‘digital’ flattering to deceive, promising much but being limited in its delivery?

The implementation of advanced train control systems such as European Rail Traffic Management System (ERTMS) is inevitable, along with the onboard technology to enable the communications with the control centres. Customers will ultimately see the benefits in terms of faster and more frequent trains, but possibly only when European Train Control System (ETCS) Level 3 and Automatic Train Operation (ATO) are achieved together.

Elsewhere, digital technology is being used to enable design verification of rolling stock. In doing so it creates a virtual reality of the journey experience that allows designers to ensure long-term passenger satisfaction.

The industry is also belatedly taking advantage of the widespread ‘sensorisation’ of trains: the rolling stock itself makes diagnostic decisions about its own health and what sort of maintenance attention it requires. In doing so, train operators can reduce unnecessary activities, eliminate the dreaded ‘no fault found’ scenario and optimise mileages for key components. Train-borne sensors are also starting to play a significant part in digital asset management of the networks, being able to report back track defects in a more efficient manner than through traditional inspection regimes.

The greatest opportunity for transformation will be in customer experience. Whilst ticketing is changing and becoming more oriented towards smart devices, the coming years will see more interaction between the train and the customer’s digital presence. Seat reservations, agile ticketing, wayfinding and augmented reality lie in wait to make the railways the transport mode of choice for the travellers of tomorrow.

Ultimately, the benefits of the digital world in the design and operation of trains will only be limited by our imagination and our ability to embrace new ways of working.

The case for Systems Integration

Zvonko Trajkovic
Americas Region Rail Systems Leader
Arup, Toronto

In many parts of the world, you would be hard-pressed to read through a newspaper without coming across an article about a rail infrastructure project that isn't facing significant programme difficulties. With huge engineering tasks, complex interfaces and numerous stakeholders (each with differing priorities), the sheer scale of these projects can be difficult to fully comprehend. An additional challenge is dealing with the rapid pace at which advanced technologies are entering the market, while designing and delivering railways that won't be operational for years to come.

Looking at experiences from a wide range of complex projects that have run into difficulties, a common theme emerges: the lack of a dedicated Systems Integration (SI) Authority that operates throughout the system's life cycle to transform stakeholder needs, requirements and constraints into a system solution.

Despite the growing evidence of SI benefits, the process is yet to become 'business-as-usual' in rail programme delivery.

Why do we need Systems Integration?

Research clearly shows that implementing SI has demonstrable benefits for large, highly complex rail projects, enabling a total systems approach to railway design and delivery.

At the start of a project, it considers all the essential elements of a railway over its entire lifespan, including the sub-systems, the interdisciplinary tasks undertaken during operations and maintenance, stakeholder needs and end-user requirements. For project delivery, SI also provides the assurance that the integrated products needed by the client are delivered to meet the specified quality, costs and timescale.

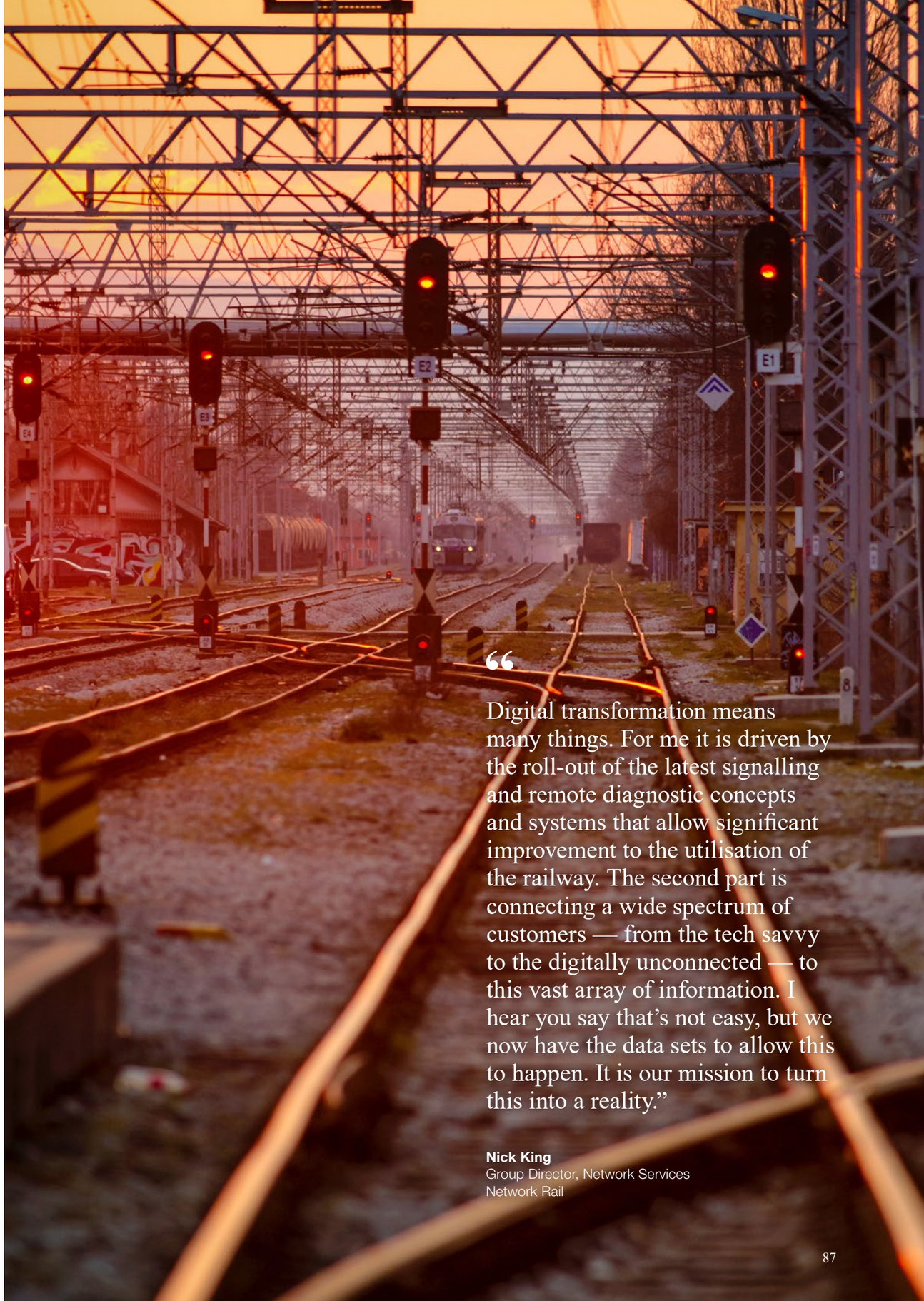
The consequences of omitting Systems Integration

SI isn't always factored in at the start of project specification and procurement, making proposals that disregard SI more appealing for stakeholders from a cost and resource perspective. However, during project delivery this omission inevitably leads to significant challenges – with risks and costs rising, and scope changes increasingly difficult to implement successfully.

The reality for poorly integrated rail systems is that costs escalate in the later stages of programme delivery and in rail operations. For example, sub-optimal assets that cannot perform as intended will create delays in full-service functionality. Concerns over safety, reliability and maintainability are also common once the railway becomes operational, with the longer-term ramifications of reputational damage and loss of political and stakeholder confidence.

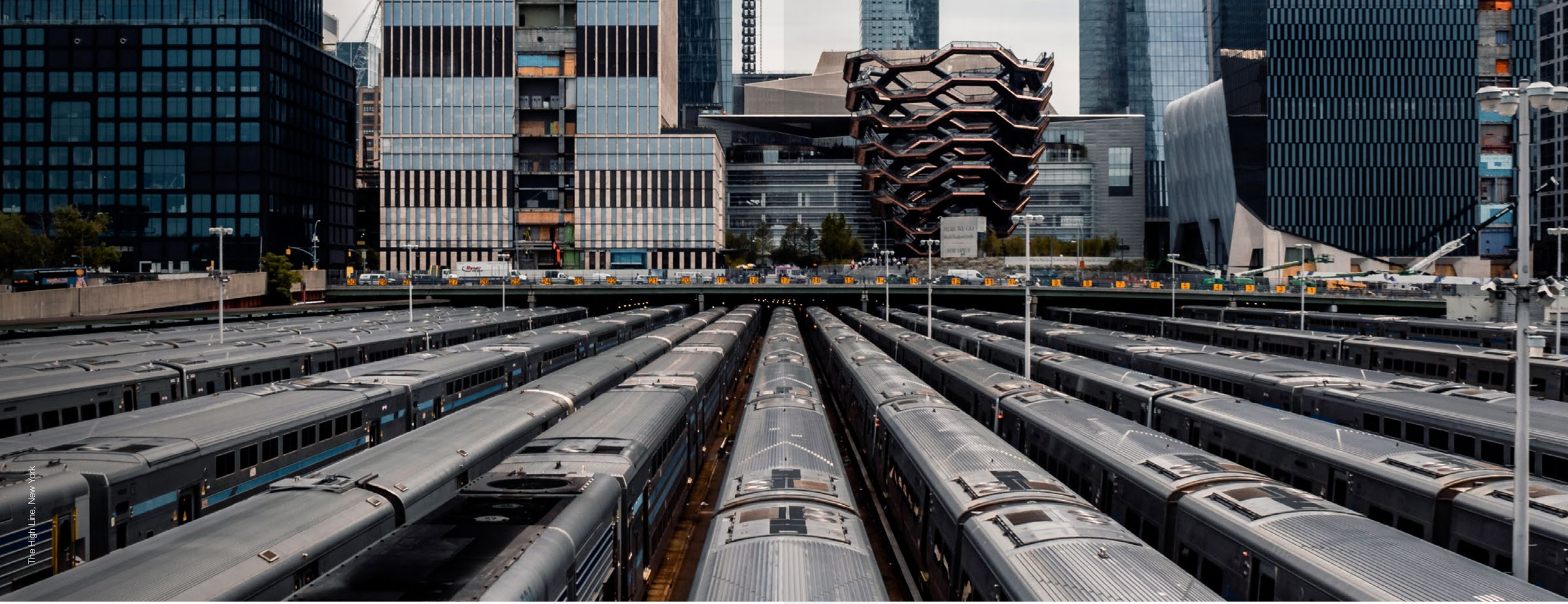
How much is enough?

How much SI effort to expend needs to be determined on a case-by-case basis, taking into account the project type, size and complexity. An extreme approach is to not have SI at all. The other extreme is to continually re-analyse and re-define every detail at the risk of delaying progress. ►



“Digital transformation means many things. For me it is driven by the roll-out of the latest signalling and remote diagnostic concepts and systems that allow significant improvement to the utilisation of the railway. The second part is connecting a wide spectrum of customers — from the tech savvy to the digitally unconnected — to this vast array of information. I hear you say that's not easy, but we now have the data sets to allow this to happen. It is our mission to turn this into a reality.”

Nick King
Group Director, Network Services
Network Rail



The High Line, New York

There is however a workable middle ground that can deliver real benefits, practically and effectively by undertaking the right amount of SI and properly balancing it against risks and project outcomes.

Traditional commercial rail projects prioritise delivery cost and timescales, with a focus on using off-the-shelf systems. The role of SI in these cases is less intensive, and it focuses mostly on ensuring compatibility across the different systems interfaces and equipment. Likewise, because the verification and validation of these systems are generally limited to standardised tests, the full Verification and Validation process is scaled down to Testing and Commissioning only.

Recent advances in rail technologies are now driving operators, project sponsors and construction contractors to have an earlier focus on total systems performance and project outcomes. This is largely due to the impact that new technologies have on the performance, reliability and safety-critical functions of the railway – all of which need a carefully planned management approach for their successful integration and implementation. As the complexity of a project increases, particularly across integration of new technologies, a thorough SI approach becomes essential to ensure that the built system will fully meet client expectations and that the railway will perform safely and reliably from day one of operation.

A voice of authority

In the instance of the highly complex projects, it becomes essential to dedicate an experienced team to lead the SI effort as early as possible. An SI Authority – a relatively new concept in the industry – acts to consolidate the business needs and integration requirements, ensuring risks are carefully mitigated at each stage of the project life cycle, and a robust operational railway is delivered.

Using a highly competent team of experienced engineers, railway operators and maintainers, the SI Authority will guide and direct the systems integration activity, provide SI management (including supervision and coordination of delivery), define the end-user requirements, oversee interface management and provide input to longer-term risk mitigation and change management.

The contractual and quasi-contractual relationships that are established for project delivery organisations need to be set up to support SI by allowing for quick decision-making and effective collaboration towards common goals. As experienced in recent light rail transit projects, the problem of uncoordinated contracts has been a major constraint to the implementation of the SI process.

The SI Authority should operate in a 'digital twin' context, where all aspects of the railway throughout its life cycle (from materials and procurement to operations and service) are fully integrated into a live online environment.

Ultimately, for digital technologies to realise their undoubted potential their application needs to be skilfully coordinated by SI Authorities. Doing so will significantly improve the delivery and performance of major rail projects around the world. ■

Arup providing HS2 Engineering support

“

Those of us focused on the resilience agenda need to promote and encourage the uptake of technologies. Where technologies are being adopted for reasons other than resilience, it is important that we work with the system owners and operators to ensure that everyone is mindful of the potential impact on resilience. We must ensure that we don’t build features into our systems now that we will regret in the future when we fully understand the implications.”

Dr. Juliet Mian
Infrastructure Resilience Specialist
Arup, Midlands Campus (UK)

A pathway to rail resilience

Savina Carluccio
Infrastructure Resilience Specialist
Arup, London

Effective transport underpins our society. Failure, disruptions or inadequate provision can cause a cascade of issues impacting employment, education, leisure, and essential services such as healthcare.[27] In this context the resilience of our rail networks is essential – particularly if we want services to continue ‘no matter what’, in the face of the diverse shocks and stresses they currently face.

We do not routinely design, deliver and operate our railways for resilience. But it really shouldn’t be an afterthought. Resilience needs to be embedded in the whole rail life cycle – from the start of planning through to ongoing operations and maintenance.[28]

To achieve this goal, a better common understanding is needed of the factors that contribute to rail resilience and how these can be achieved in practice.

Improving resilience increases the ability of rail systems to withstand potential threats and recover quickly from disruptive or extraordinary events. A consistently reliable service and asset is the ultimate aim. Industry interviews by the Resilience Shift[27] highlight where resilience is already being built into the rail system, along with recommendations on potential actions to further increase it.

Digitalisation offers opportunities for improving how we plan, design, build, operate and maintain our rail systems in a more resilient way. For example, embedded sensors now provide real-time feedback into rail infrastructure; and advanced modelling and analytics enable condition-based and predictive maintenance. These technologies enhance the resilience of rail networks, by reducing the potential for human error – making systems faster, smarter and more adaptive – before, during and after an incident. As an illustration, Japan’s earthquake early warning system can cut power and apply emergency brakes to trains in the first seconds of a seismic event, to avoid derailment. However, as rail systems become increasingly sophisticated and digitally-connected, their complexity increases. Digital systems overlain onto legacy infrastructure won’t remove pre-existing and underlying vulnerabilities. Conversely, they may introduce new issues which can lead to disruption and other unintended consequences. As just one example, digital technology such as the European Railway Traffic Management System (a continuous communication-based signalling system) could present opportunities for cyber-crime if not managed effectively.

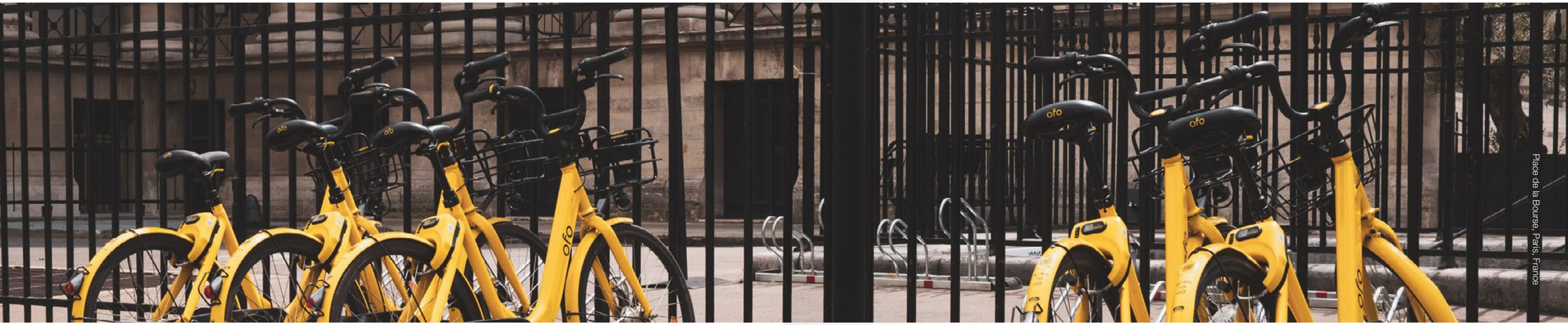
With this in mind, if digital technologies are not to undermine system resilience, their introduction and planning must be grounded in a deep understanding of the systemic context. Balance is also vital. The need to make digitally-connected rail systems more resilient must be weighed against the broader benefits of digitalisation and its positive impacts on service.

Going forward, the focus must shift to how to ‘do resilience’ in practice. Practitioners and decision-makers will need to design and implement strategies that find ‘sweet spots’ between resilience, sustainability, efficiency and the safety of the railways during operations. These strategies will help making a compelling case for resilience.

Resilience in rail requires consideration of technological, societal, organisational, environmental and physical systems. It cannot be managed solely at sector level or by engineering interventions. It needs a long-term view as well as a whole-system, cross-sectoral approach involving multiple stakeholders. Key interdependencies, such as the reliance on the power network, also need to be actively managed.

There is still some way to go, but if industry stakeholders across the infrastructure value-chain work together to integrate resilience into their existing systems and decision-making, it will clearly benefit everyone.

The role of rail in the age of MaaS



Kazuki Aiba
Engineer
Arup, Tokyo

Mobility as a Service (MaaS) promises to tackle some of the challenges of growing urban populations, and at the same time give users greater control of their individual travel needs. Convenience, personalisation, simplified ticketing, and savings in both time and money are among the potential benefits. The introduction of MaaS is also expected to result in an increase in the use of public transport and a decrease in car ownership, with positive impacts on CO_2 emissions. It could also see land currently allocated to car parking transformed into green, interactive spaces.

Making MaaS a reality, however, needs public and private stakeholders working together in new ways. Only through coordinated data sharing can user journeys be personalised and optimised across the range of mobility modes. But what will the role of railways be in the journey towards a MaaS future?

The big idea

The main goal with MaaS is to bridge the gap between rail networks and other mobility modes like shared bikes, taxis, e-scooters, transportation network companies (like Uber or Lyft) and Autonomous Vehicles. This would be facilitated through a single digital platform, giving users access to timetables, routes, ticketing and other travel information – such as real time road traffic on their personalised route. As an example, upon arrival at a train station, a pre-paid autonomous taxi would meet the passenger at the station and take them to their final destination via the least congested route. The vision for MaaS is for seamless journeys made via complementary transport modes, managed entirely on one app. To make this a reality, data will be key.

Making it happen

Looking to Japan as an example, a multitude of public and private rail operators each have their own contactless smartcards for ticketing, a useful data source for operators. Beyond payment functionality for rail journeys, these cards are frequently used in restaurants and convenience stores, providing further data that could be used to continuously improve customer experiences.

With MaaS, the scope of big data acquisition could extend beyond the railway to other operator-owned services such as real estate, hotels, buses and taxis around the station, providing many more data sources. But coordinating and managing data – and associated privacy risks – at this scale requires multiple parties coming together.

Ultimately, the success of MaaS relies heavily on the local political context (as discussed in further detail in the recent report *The Future of Mobility and MaaS Governance and Orchestration*[29]). The success of Whim in Helsinki or Jelbi in Berlin, for example, can be attributed to the proactive involvement of the local governments.

One of the biggest challenges for achieving MaaS in countries like Japan and the UK, where there are multiple players with different needs, is bringing public and private stakeholders together under agreed governance and commercial frameworks. Other challenges include ageing populations, many of whom may not own smart devices, and resistance from transport companies that are used to traditional operations. We can, however, learn from success stories like Whim. Built around a MaaS subscription model, it sees users paying a fixed amount every month according to usage frequency, which benefits both users and operators.

The automobile industry is rapidly shifting towards a future known as CASE (Connected, Autonomous, Shared and Electric). In this world the railway industry needs to become more data-driven to remain competitive. MaaS will certainly be a key component of future innovative railways. It's important that we create the conditions to make it flourish.

Second Avenue Subway, New York

Chapter 5

Financing and funding

Who pays for our railways?

Transport is often considered an essential public service that is expected to be reliable and affordable. But such a service requires continual improvement and investment in refurbishment and new infrastructure – and this is where the challenge begins.

Building, operating and maintaining transport infrastructure is costly; farebox revenues can cover only some of the operating cost, and significant upfront capital is needed. The demand exceeds the public funds available, so governments seek to engage the private sector.[34,35] However, public investment still commands the funding in most of the world. In 2016, for example, 70% of European rail infrastructure funding came from national budgets.[36]

Infrastructure projects have characteristics that can make them unattractive to investors. Understanding these features – their connected risks and how various policies and incentives can aid in their mitigation – is essential to unlock private capital and encourage long-term public/private cooperation.

In the shoes of the investor

Convincing investors to commit to a long-term endeavour with unpredictable timescales that can cause extended delays before any return on investment can be quite a task. Transport infrastructure projects require significant upfront investment and the time-lag between planning and actual operations is years, or even decades. Numerous parties are involved, often with conflicting interests, and if there is a lack of coordination, there can be cost and time overruns. Moreover, there is a significant political dependence and a complex regulatory landscape. All these risk factors will affect a potential investor's decision.

The main categories of risk identified by OECD for infrastructure projects are:[37] political and regulatory; business and macroeconomic; and technical.

The actual sources of risk are asset borne, contracts with the public sector, and exposure to the environment where operations are taking place. Stakeholders should undertake risk management according to their expertise, but often they try to offload it.

The challenge in transport schemes is that the main investor is not necessarily the primary beneficiary. Risks are high and profits are uncertain, but if procurement, financing and funding become aligned with the economic, legal and cultural landscape, they can succeed.

Creating conditions that encourage investment

Innovative financing and funding tools such as new revenue streams, economic incentives, regulations that favour shared risk management and use of the latest technologies to facilitate project delivery can improve long-term cost-efficiency and help to de-risk the investment. This is ever-more needed in an age when new infrastructure is continuously built to support global urbanisation andthe capacity of the construction sector is reaching saturation, adding to overall cost. ▶

At a glance

Measuring success
Defining and measuring what success means for government, business and communities

Capturing land value
Finding new ways for land and property to fund major investments

Combining financial resources
Optimising the balance between private and public funding

Encouraging investment
Addressing the issues that will bring rail investors on-board

Finding innovative ways to finance
Combining new revenue streams with incentives and shared risk

Informing the business case
Using new tools and technology to build stronger business cases

Building stronger partnerships
Creating favourable conditions for private/public sector collaboration

Opposite
Century Gateway, West Rail Tuen Mun Station, Hong Kong

To avoid further increase in cost and funding demand, efforts must be directed towards innovating the entire sector, currently one of the least digitised industries worldwide. Digitisation and research and development in new construction technologies and techniques can drastically improve the productivity performance, and potentially drive down the costs.

Potential investors want to see a strong business case, but the relevant information is often unavailable. For example, cost-benefit analyses of railway schemes are frequently incomplete or subject to assumptions (which depend on various economic, social and environmental factors). Although it is assumed that rail generates economic growth and value, capturing and quantifying this value remains a challenge (see ‘Measuring and maximising success’ p. 110). For example, The Australian Centre for Transit-Oriented Development (CTOD) estimated a value uplift of +9 – 167% for retail properties in proximity of a station,[38] while Crossrail estimates a 18% property value uplift within one kilometre of an Elizabeth line station.[39] However, care needs to be taken to ensure local communities are not pushed out by the increases in land value that attract investors (see ‘Rail (really) for the people’ p. 45). This cost is intangible and does not impact the investor’s balance sheet (at least not immediately), but it cannot be accepted if railways are to be fully sustainable.

Public rail or private rail?

Should railways be national or privatised? In the long-term, the ownership structure and appropriate legislation may affect the efficiency of operations. There are examples of success on both sides. Spain or China support the idea of national railways, while Amtrak in the US is a good example for the involvement of the private sector. On the other hand, in the UK, the promise of a better service because of privatisation arguably failed to materialise and a review is underway.

Japan, Singapore and Hong Kong have some of the most successful rail systems, characterised by a mix of national and private incentives. In Japan, railways are owned by private companies, but the government created favourable conditions for the generation of revenue through property or retail. Similar cases are found in Singapore and Hong Kong. Private and national sectors are each aware of their potential and limitations, and work together to maximise the chances for success. Overall, strong partnerships are crucial from the start to ensure the successful delivery and operation of the transport infrastructure. ■

70%

of European rail infrastructure funding came from national budgets in 2016

18%

estimated uplift for retail properties within 1 km of an Elizabeth line station

King's Cross Station, London

Attracting private investment into rail

Alexander Jan
Chief Economist
Arup, London

Railways are greedy for capital. They require lots of materials, labour and capital equipment, which all cost money. With an explosion in global demand, rail projects often end up competing against each other for investment.

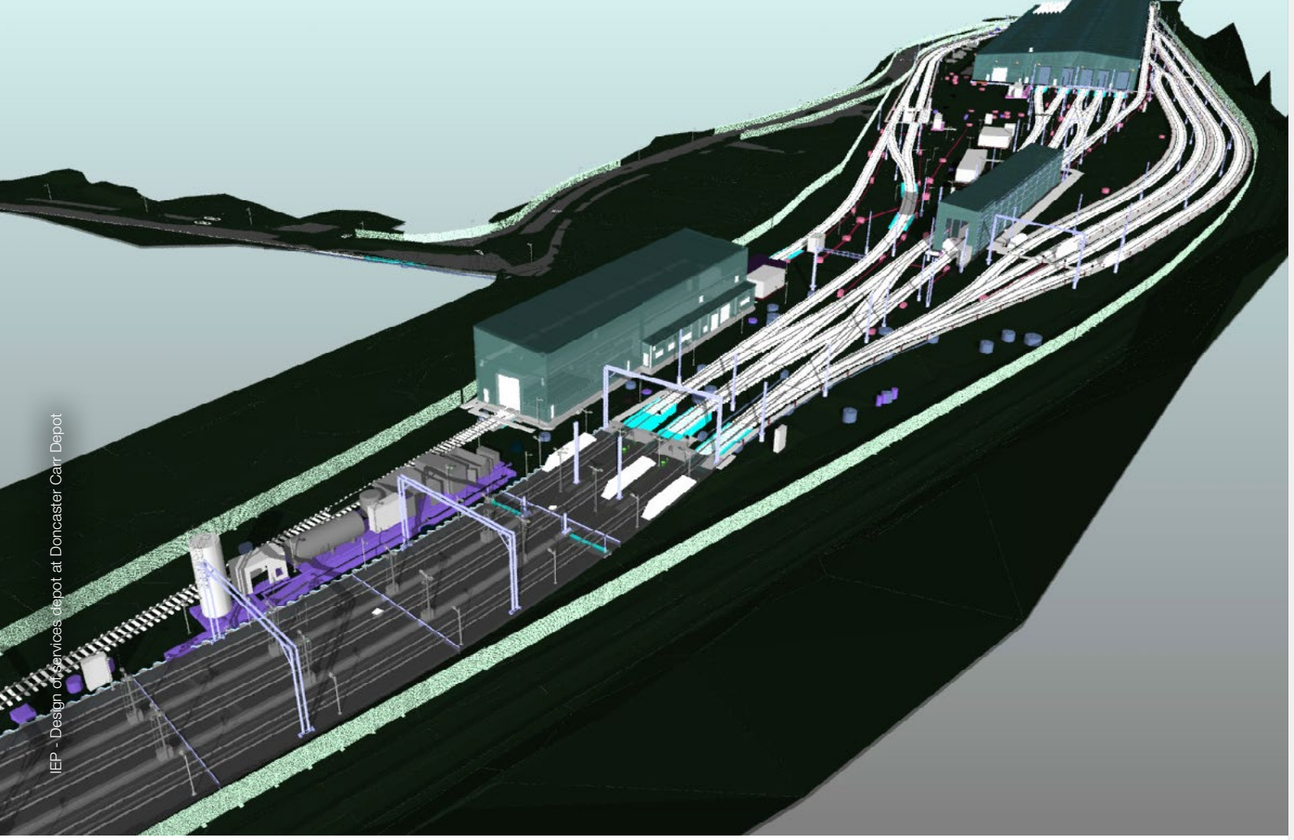
The financing and funding of rail tends to create headaches for cities and corporations looking to get their schemes off the ground. A well-thought-out investment approach to rail financing and funding can create incentives that will unlock the wider value that rail projects can bring to the economies and communities they serve. However, how that value is captured is a balancing act. The mix of land and property taxes and charges, real estate development options and farebox revenues required to fund a rail project is wide and varied.

Government policy interest in combined development and land value-led models for railways is increasing. Next to direct user benefits of a new line – such as faster rail journey times – decision makers are thinking early on about the real estate development case. These days, it might even help to determine the alignment of the scheme. So increasingly, value capture, in its various forms, is playing a greater role in helping to pay for new schemes.

But generating revenue is only one side of the equation; the other is controlling costs. In this context, different procurement models that harness the strengths and capabilities of the private sector can help to bring in projects closer to budget. Getting the incentives right in using tried and tested technologies, modular design, sensible innovation or solid contracting set-ups can make the difference between projects staying in the black or going bust. Ultimately, getting a rail scheme from the drawing board into service demands an almost magical mix of skills, resources, foresight and luck. But it all starts with the question ‘Who pays and how can we finance our railways?’

To find out more, read our *Rethinking Transport Finance and Funding* report.

Edinburgh Waverley Station Infrastructure Enhancements, Scotland



IEP - Design of services depot at Doncaster Carr Depot

Can BIM reduce the railway funding gap?

Jorge Macedo
Senior Consultant
Arup, New York

Building Information Modeling (BIM) is the process for creating, managing and sharing information throughout the life cycle of a built asset. This data enhances the ability of asset managers, owners and investors to generate profits and, by extension, the efficacy of available fund sources.

The benefits of BIM implementation during the planning, design and construction phases of a project have been well documented. Improved visualisation, multidisciplinary collaboration, design quality and early clash detections are some examples. Digital models enable operators to maintain a complete and dynamic asset inventory that includes an up-to-date integrity, maintenance and reliability history of the asset's components. This results in reduced downtimes and maintenance costs and improves overall asset performance.

To fully realise the benefits for upfront investments and life cycle costs, the infrastructure community needs to embrace the universal and coordinated adoption of BIM. The most effective use of BIM will require the various departments within owners and government organisations to become well versed in the use and capabilities of digital technologies. Some governments and owners already mandate the use of BIM on all their projects, and we anticipate this trend will continue.

BIM software developers and consultants are aware of the long-term value of BIM. They can work with owner and government organisations to diagnose their digital needs and gaps, implement the right systems and procedures, and most importantly, help drive the organisational transformation to fully leverage the life cycle benefits of BIM implementation.

Is transit-oriented development (TOD) the solution?

Gaurav Ahuja
East Asia Business &
Investor Advisory Leader
Arup, Hong Kong

Jason Wong
Director
Arup, Hong Kong

There are few examples of financially sustainable public transport projects around the world, with the Hong Kong and Singapore mass transit systems being notable exceptions. These systems have generated an average annual return for shareholders of around 9% and 11%, respectively, over the past five years.[40] Exceptions aside, rail typically requires financial support from governments, which – faced with multiple funding requests – are under increasing pressure to look for innovative ways to fund infrastructure projects.

The success of transit-oriented developments (TODs) in markets such as Hong Kong and China has created excitement about the opportunity to leverage such models into other markets. However, local nuances influence the outcome. Hong Kong and China benefit from a combination of high population densities, high property prices, an effective rail network, and government ability to appropriate land and contribute it to TOD projects at 'pre-railway' valuations.

The TOD at Kowloon station in Hong Kong is arguably one of the better global examples of effective place-making and robust financial outcome. It encompasses a transport hub that includes an airport rail link, subways, buses, rail connections, and taxis. It also encompasses hotels, office towers, a high-end retail mall, food and beverage venues, and apartments that can house up to 20,000 residents. Kowloon station is indeed a mini-city in itself.

Japan is another market that has reaped the benefits of TOD, particularly in inner Tokyo. However, Japanese companies approach TOD from a different perspective. The focus is not on real estate assets, but on mapping the activities of residents and workers along rail corridors and establishing assets and businesses that capture a high daily proportion of passenger spend. For example, Tokyu Corporation, whose assets include the Tōyoko, Meguro and Ōimachi lines, owns department stores, supermarkets, hotels, banks and property developments along its rail lines. Thus, it generates revenue every time passengers move in, shop, travel or eat along the rail lines. In 2015, Tokyu Corporation secured the concession to operate the Sendai Airport around 330 km south of Tokyo, which no doubt offers further opportunities to 'follow the passenger'.

The Japanese approach is a private sector alternative to land value capture (LVC), which has typically relied on governments funding the rail infrastructure and subsequently realising returns through incremental taxes or rates on higher property values along the alignment. The traditional LVC approach is difficult to achieve in emerging markets, where accounting records and land valuations may not be properly regulated. The Japanese model could be a viable alternative for these markets, but it would require an ecosystem of investors with an eye for long-term returns.

TOD is an elegant solution to integrated urban design, but it is not the perfect financing tool unless a specific set of conditions exist. The Japanese LVC model might present a more effective alternative.

In conversation

The innovation funding package

Three young Arup economists discuss the future of rail project financing and funding, looking at the involvement of the private sector and the key role of collaboration.

Joanna Jedrasiak
Senior Economics Consultant
Arup, London

Victor Frebault
Economics Consultant
Arup, London

Patrick Andison
Economics Consultant
Arup, London

How can rail attract investors?

JJ The key thing to change in the perception of rail and other major transport infrastructure projects is that they are not about transport for the sake of transport. Transport investment is not just about generating time savings for its users. Modern rail projects need to be considered as tools to achieve much wider, strategic goals on a whole city level. Rail is a means of delivering economic growth, jobs, homes and a better quality of life to the areas in which we live. If that is not our focus, and part of the focus of a funding strategy, then we are falling at the first hurdle.

PA Precisely. Rail decision-making needs to be integrated with strategic city planning and support cities in achieving their goals and overcoming challenges. The starting point is not that we want to have a new metro line. The starting point is identifying the long-term outcomes a city wants to achieve. These include a variety of goals: increasing the number of jobs, number of homes, regeneration plans, increasing general connectivity, decreasing pollution and congestion. Transport solutions need to be designed to maximise those wider economic benefits, which can then be tied back to the funding package of a major rail project.

VF When developing a rail line from the outset, practical engineering must be combined with strategic transport advice, economics, demographics and city planning. This approach also needs to incorporate data analytics and insights using tools to test wider outcomes along different corridors. Evidence-based planning should support the route selection and the type of services a new rail line offers. And a benefit realisation strategy should be put in place, at the design phase of a rail project, to check that the delivery of growth outcomes is synchronised with construction of the scheme.

You speak about bringing disciplines such as economics, engineering and transport planning closer together from the outset. What does this collaboration enable?

VF By ensuring integration between these disciplines, you ensure that people will want to use the new service, that it will have a positive social impact, and that it can be funded and operate sustainably. A cross-discipline multi-criteria analysis builds the holistic understanding required to properly choose between the route corridor, station location and type of services that are being evaluated. Economics and planning should directly contribute to engineering workstreams, which means that the development of the scheme must directly complement the business case, and vice versa.

JJ Approving and implementing major rail investments is ultimately a political process. Early and wide-reaching engagement with stakeholders, including the business community, is essential. Building a successful political case for rail investments boils down to: building a coalition; encouraging strong city and regional leadership; making the widest possible case to align planning with financial incentives for local authorities; having a narrative on infrastructure investment; and remembering that this is a political process.

PA Individual and institutional political leadership are necessary to drive the success of transportation projects. Of vital importance is the presence of a focused and dedicated team, tasked solely with progressing the rail project and capable of building strong connections with a diverse network of stakeholders. Pioneering approaches to developing business cases for rail infrastructure that integrate private sector funding will help to mitigate the public sector risk of an unviable business case.

So, what is the role for the private sector in the funding of future rail infrastructure? How can we enable the public and private sector to work together to deliver new rail projects?

VF The private sector plays a critical role in the future of rail infrastructure across the world. Whether as a direct contributor to rail projects or providing investment support through long-term financing arrangements, the private sector can help to push projects forward and enable their delivery. We expect that viable funding packages for ambitious rail projects will include a series of funding mechanisms from various types of beneficiaries as well as contributions from the public sector.

PA Absolutely, but this all depends on developing a clear and effective case for 'why'. Experience shows that developing a case that the public understands and buys into is extremely important. When we look at recent cases like Crossrail, an effective case meant that private sector leaders were actively looking to find ways to help fund and deliver the project.

JJ Crossrail was all about delivering transport infrastructure that would enable the future economic success of London and the UK. The scheme was understood to be beneficial to the city and critical for the future economic growth of the UK. Private sector leaders like Canary Wharf and the City of London became some of the greatest advocates for the project and were advocating for additional taxation on their businesses to help ensure the project would be delivered.

How do we ensure we are generating funding for ambitious rail infrastructure projects that are delivering the best outcomes?

VF In 2016 voters in California were asked whether they would accept an additional levy 'to improve freeway traffic flow/ ▶

"Rail is a means of delivering economic growth, jobs, homes and a better quality of life to the areas in which we live. If that is not our focus, and part of a funding strategy, then we are falling at the first hurdle."

Crossrail Place, London

safety; and expand rail/subway/bus systems' among other initiatives. The transit tax passed, with 72% of voters approving 'Measure M' (a sales tax ballot measure). Despite available funding, history has shown that transit tax promises may remain unmet. Voters might love transit, but that does not mean that they plan to ride it.

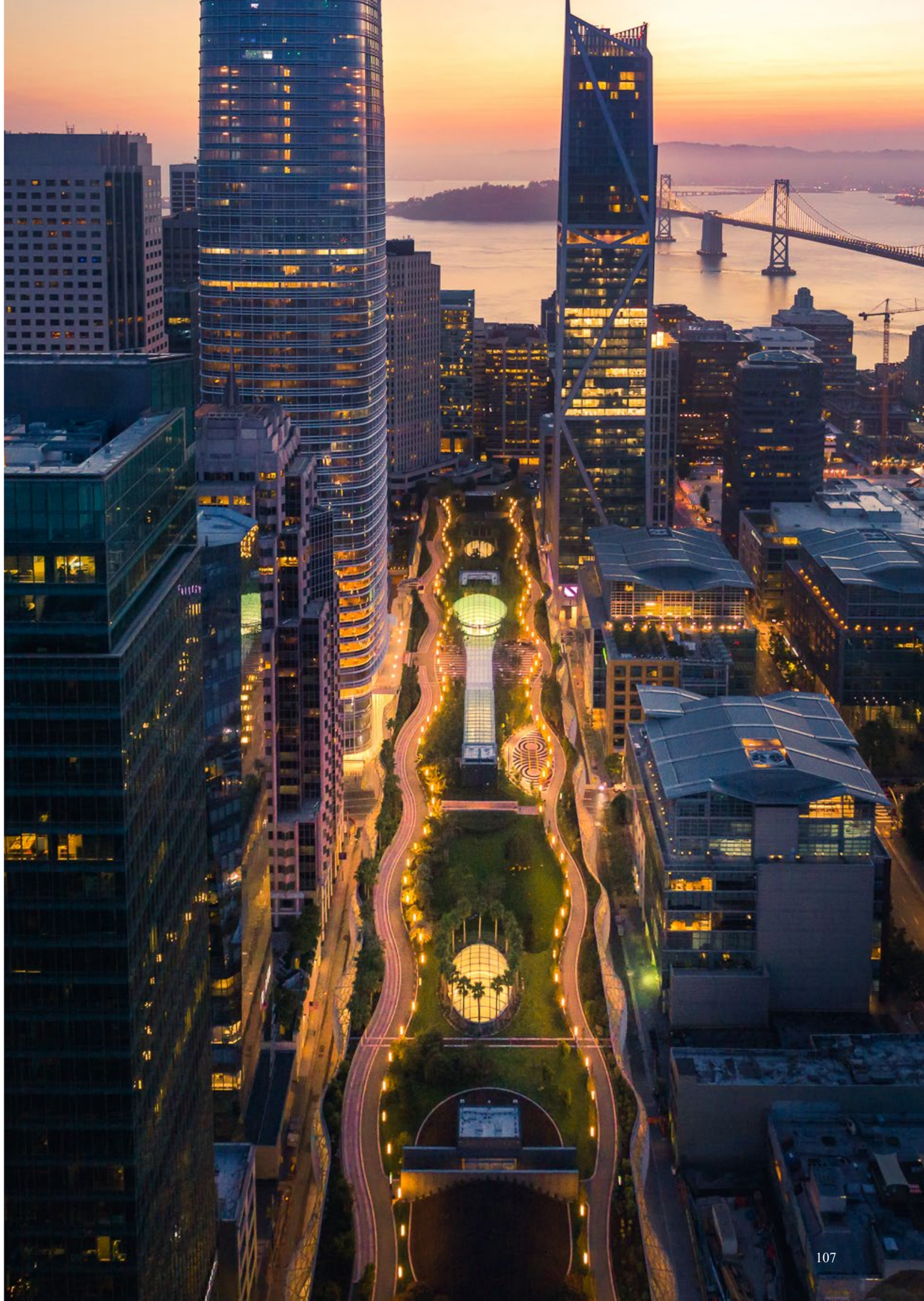
JJ Pressures on public budgets often mean that ambitious transport projects are de-scoped to reduce costs. For a rail line, this could mean decreasing the number of stations, the speed and frequency of services, or changing route alignments. This is often done to the detriment of the strategic and economic case for these projects, as the wider economic benefits and the potential to unlock value are not considered appropriately throughout the development of a project.

VF Tying the economic outcomes of rail infrastructures to their funding mechanisms ensures that projects are thought about more ambitiously, focusing on the potential for growth and associated capturable benefits of investments. The alternative is de-scoping projects that would achieve sub-optimal outcomes, reducing incentives for the private sector to contribute.

If there is an effective transport case, how do we expand the menu of available funding options to enable a more innovative funding package?

VF During a recent feasibility study, we discussed with our client developing a list of 100 ways of raising £1 million. While many of these initial ideas seemed unfeasible, impractical or downright silly, the exercise was incredibly worthwhile. As has been shown through recent success stories, creative approaches to developing a comprehensive funding solution, made up of various innovative and traditional components, is key. Putting creativity and innovation at the heart of the way we approach and work, to find solutions to challenges of funding infrastructure, is essential to our future success.

PA The good news is, this era of creativity and innovation in funding and finance is part of a very exciting period for transport infrastructure. It will reshape the way we think about the goals, delivery and funding of our transport infrastructure needs. ■

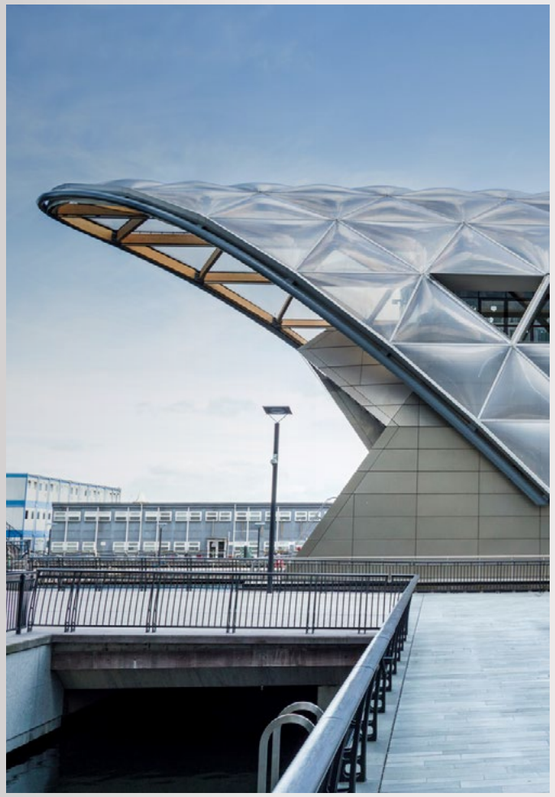


Transbay transit center
San Francisco, California, USA

Adaptable carriage for off-peak light cargo

42 Technology, together with the UK's Rail Safety and Standards Board, have developed a carriage with a flexible seating system that allows off-peak trains to carry 'low density, high demand' goods and opens up new sources of revenue. The system has been designed to allow seats to be automatically stowed in the carriage, making space for cargo. Seat elements are not mounted to the carriage floor, maximising available space and making provision for the potential use of Automated Guided Vehicles (AGV) to pick up, transport and deliver the goods. Flexibility and modularity allow the layout to be adjusted to the number of passengers, without compromising the comfort and safety of travel.

This new approach could generate up to £15 billion annual revenue, based on the unused passenger capacity going in and out of London stations only. The technology could help ease road congestion, cut emissions and provide faster delivery times for online customers.



Land value capture tool

Land value capture (LVC) studies occur too late on infrastructure projects as they are expensive and difficult to do. A conventional planning process enables analysis of scenarios usually derived from a single initial idea, a time-consuming process dependent on the quality of the initial idea. Due to the linear nature of the process, it is expensive and difficult to alter once scenarios have been defined. Planning processes could be more effective if they allowed the testing of several scenarios at the initial stage, funnelling refined solutions to a final recommendation.

The solution is software that uses property tax data to estimate the LVC potential for each alignment, and model the impact of new commercial and residential developments. It will also quickly estimate construction costs and compare options to help clients understand key issues in a visual and compelling way. This functional tool will allow the user to select a city and create basic metro alignment options based on value capture.

Top
42 Technology's adaptable carriage design concept

Opposite right
Canary Wharf Crossrail station London, UK

Right
Gautrain's 80km rail system South Africa

The Luxembourg Rail Protocol to the Cape Town Convention on International Interests in Mobile Equipment

The sustainable development of Africa and meeting the requirements of massive urbanisation and population growth are reliant upon the creation of an intercontinental rail network throughout the continent. Current infrastructure needs are huge, but with median public debt reaching 50% these cannot be financed by the state.

Private sector involvement is needed, and suitable conditions must be created to help offset risks. The Luxembourg Rail Protocol, a result of the Cape Town Convention on International Interests in Mobile Equipment has the aim of regulating the security interests of lenders, lessors and vendors. The protocol is expected to increase the amount of capital available for railway assets.

A new International Rail Registry, with unique global identifiers for all rolling stock, will enable financiers to register their interest in specific vehicles. This should also facilitate greater foreign investment, since the same regulations will apply in the lender's country of origin as well as the countries in which rolling stock will be in operation.

Measuring and maximising success

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Michael Peasland
Associate Director
Arup, Milan

Defining success for a major rail project is more complex than many would first imagine.

At its simplest, success means delivering the business and wider benefits originally envisaged – on time and on budget – with no downgrade in scope. But there are other factors to consider too.

When it comes to performance indicators, matching or exceeding ridership predictions is always key. This is as important for small light rail as it is for big intercity projects, and also for freight. Attaining this goal is indicative of a project that was well conceived, well designed and constructed to achieve seamless connections, with competitive travel times and efficient operations.

It is also important to consider success in a wider context. Both heavy rail and light rail are integral to successful urban mobility initiatives, tightening the fabric of the city in a way that other transport modes cannot. Measures of success for these initiatives include: alignment with the city's long-term vision; permanent and measurable modal shift (away from cars); increased accessibility and usability of cities for users; integration of various transport modes into an efficient system. Overall contribution to the city's economic growth, attractiveness, and liveability are also success indicators. It's also important to acknowledge the contribution to the redevelopment of more challenging parts of a city like former industrial areas or rail yards.

In total, these broader urban mobility measures may sound like qualitative performance indicators. However, there is scope to quantify them within a framework, allowing everyone to objectively assess the success of a scheme, particularly the rail components.

Maximising the chances of success

Managing expectations is essential to long-term success. A lot of projects disappoint their stakeholders because the expectations are unrealistic – especially when it comes to scheduling. This is compounded by multiple stakeholder views. A better strategy is to set realistic expectations coupled with intensive and genuine engagement with all parties, so that everyone has trust in the project development process right from the start.

Successful projects also need the active engagement of political leadership at key junctions, to prioritise project funding, or resolve inter-agency issues. From a governance perspective, at the project development and delivery level, it is important to decouple the project from the political leadership as far as possible. Decision-making that affects things like on-time and on-budget delivery and quality of service to the end users should usually be taken by the management team, subject to a system of performance metrics.

An important feature for success is independent advisers and engineers who can challenge the board and project management teams ahead of making important decisions, and who can verify the actual performance. Such a system of independent assurance inherently drives discipline in better risk management, including mitigating political risk.

Another critical success factor is strengthening the value and effectiveness of the upfront stages of the project. Strategic thinking is essential here, ensuring that policies and procurement strategies reflect the modern challenges we face. Integrating the UN SDGs principles at the core of a project is one example of what this means in practice. Holistic economic insights, which ensure that the project is 'bankable' are also paramount. These ensure that a project's value is captured and drop down at the evaluation stage.

GO train, Toronto, Canada

We must also be careful to time and place our upgrades and new infrastructure to meet the needs of growing cities without going too far ahead of demand, or pre-placing expensive rail infrastructure in speculative places. Business cases are a challenging issue here, particularly when moving expensive investments ahead of demand. A sequenced and ramped approach to service delivery is part of the answer. Integrated planning mechanisms and empirical economic logic are also important.

Aligning interests

Rail projects involve many stakeholders: the end user; the city and regional government agencies; consultants; the general contractor and the various suppliers. Ideally all the interests of this chain would be aligned, but there can be competing interests.

On a political level, democratically elected leadership typically changes much more quickly than the time it takes to plan and deliver a rail project. The best strategy is to focus early on building wide support for the project among the general public and the key stakeholders.

When it comes to different transport modes, competition can be challenging. In Canada, there are some municipal operators that provide several modes – Metrolinx in Toronto is one example, operating the GO Train and the GO Bus. However, this is certainly not the situation everywhere and the priority should always be maximising ridership. As an example, the State of California's Rail Plan, published in 2018, calls for a series of capital investments to improve physical connections at key nodes, as well as changes to operations and inter-operator agreements to achieve a seamless and fast system from a user perspective.

Ultimately, in order to manage our long-term relationships and stakeholders, we must better understand the 'customers' and 'beneficiaries' and the differing roles of the partners and partnerships involved. In mass transit and urban mobility, the customer extends far beyond the passenger.

Understanding this hierarchy of beneficiaries is the key. Transport cannot always be considered as modal, when stakeholders are involved. Understanding the needs of the city and region and the economic customer needs is vitally important, and always ranks above modal considerations.

In general, better service can and should be aligned with increased revenue, and this can be acceptable ▶

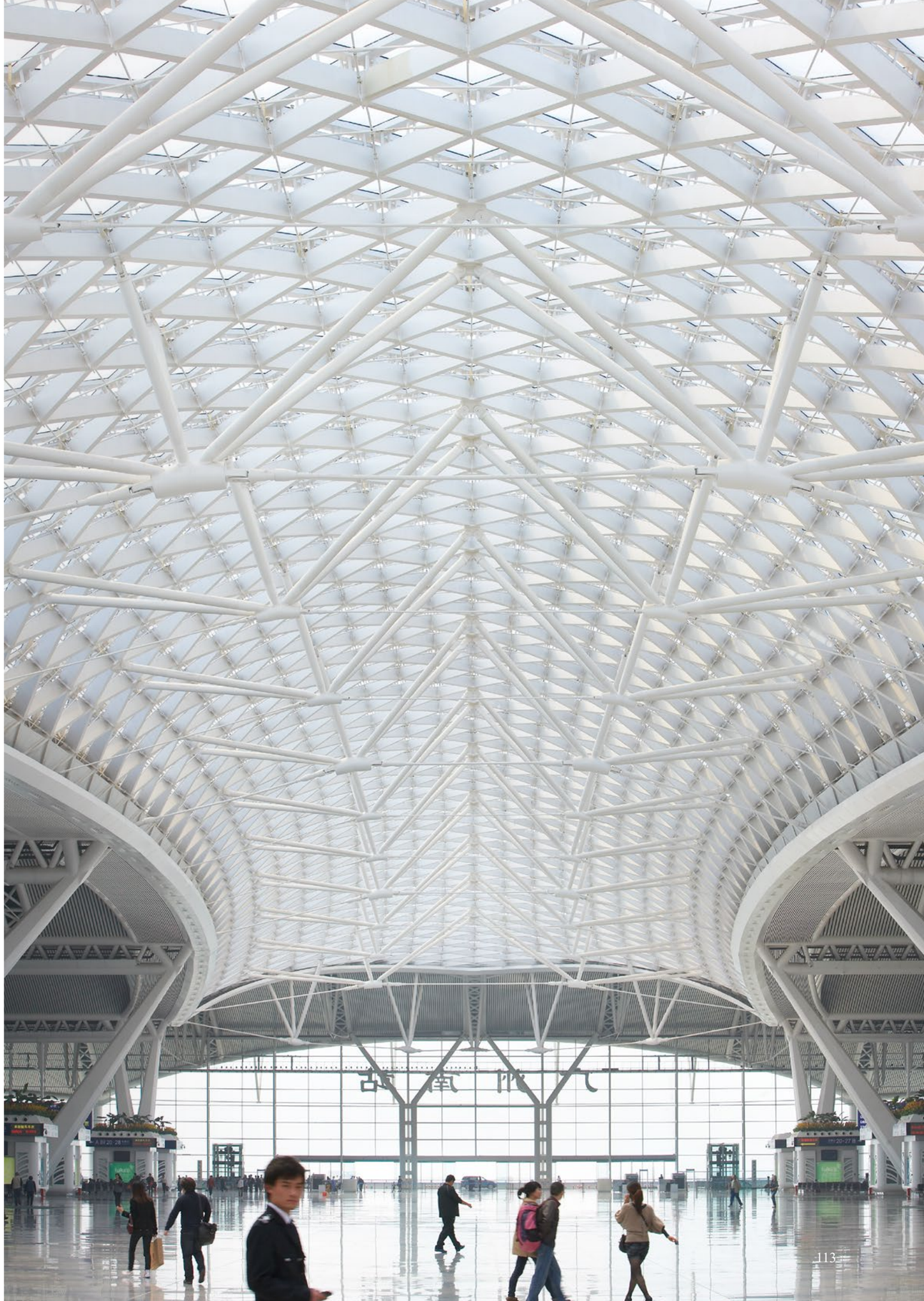
to both passengers and the wider customer if the message is brought to market in a logical and mindful way. The various customers must be at the heart of decision-making and should be informed and involved, so that there can be a ‘bargain with the customer’ around the costs of improving transport services.

The future of finance and funding

There is no silver bullet. With few exceptions globally, urban rail projects do not generate sufficient revenues from their own operations, and thus need a diverse mix of funding and financing sources to succeed. In contrast to funding, financing is relatively easy, as often the financial systems and markets can come up with solutions that respond to the funding plan of a given project. Problems can arise, but these tend to be either regulatory or political.

The real challenge is the funding plan and the challenge of capturing the economic value created by the rail investment itself. Approaches can be categorised into two groups: value capture from taxpayers and value capture from developers. The first category includes mechanisms such as land/property value tax. The second category includes mechanisms such as selling or leasing publicly owned land in the project’s influence area or selling or leasing air rights. These mechanisms can be combined and scaled, and are financeable. Mega-projects such as Crossrail in London have funded more than one-third of their capital costs with these mechanisms. The key is that the optimal project strategy should follow an integrated approach that puts the end user and the economic benefits front and centre.

Finally, it is important to note that rail projects are realising more and more of the value of partnerships with the private sector. ■



Guangzhou Rail Station, China

Afterword

Paul Coughlan
Chief Operating Officer
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The golden age of rail, which reached its heyday in the early decades of the last century, still holds a romantic fascination for all of us. But we also appreciate the political, financial, design, construction and operational challenges that were overcome to deliver a global network of railways. Railways drove the development of the world economy and the globalisation of society during that era.

A century later, the context is very different but the challenges of creating and operating new railway systems, or of delivering complex renewal projects, have a familiar feel about them. The demand for travel remains undimmed in an increasingly frictionless world. Meanwhile, we face existential environmental challenges, which demand workable solutions. Rail can help meet these challenges. However, despite the resurgence of rail as a transport mode, projects remain complex, difficult to fund and time-consuming in their delivery.

Sustained political support and clarity of project strategy remain key success criteria, the achievement of which will require us to transcend institutional and regulatory constraints. The complexity of the modern stakeholder environment means we must work harder to harness that critical mass of support that will carry a project through the many obstacles that lie in its way, but the skills to achieve it remain fundamentally the same as they were in that golden age. We must compellingly argue for the project, skilfully making the case for its broader socioeconomic benefits, and for rail as a transport mode that meets the needs of the future.

We must also deliver. Appropriate client-side capability and capacity needs to be built if project ambitions are to be realised. Railway systems have never been so complex, and this means that we need to build holistic frameworks for delivery at the outset of projects that may take a decade or more to realise. Early and sustained stakeholder engagement will generate the support essential to project success. The importance of a robust procurement strategy remains underestimated, but it generates tangible momentum when in place. And we must embrace new technologies, pushing the boundaries of our understandably conservative design and operational philosophies.

I am convinced that we are at the beginning of a new golden age of rail. Its strong sustainability credentials, allied to its ability to move people efficiently and at speed within our increasingly urbanised world, will make it the mode of choice for commuting or for inter-urban travel in the immediate future and beyond. This presents a unique challenge to those of us responsible for conceiving, designing, delivering and operating railway systems. Rail has the capacity to transform lives, businesses and communities. Ensuring that capacity is realised is the challenge ahead. By focusing on systems thinking and putting people at the heart of everything we do, I'm confident it's a challenge we can meet.

Cambridge platform extension, Cambridgeshire

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