Jernbane-
direktoratet
Norwegian Railway Directorate

Digital twins

Railway use cases and ways to enhance an asset-heavy sector

Executive summary

Digital Twins Can Transform Railway Performance

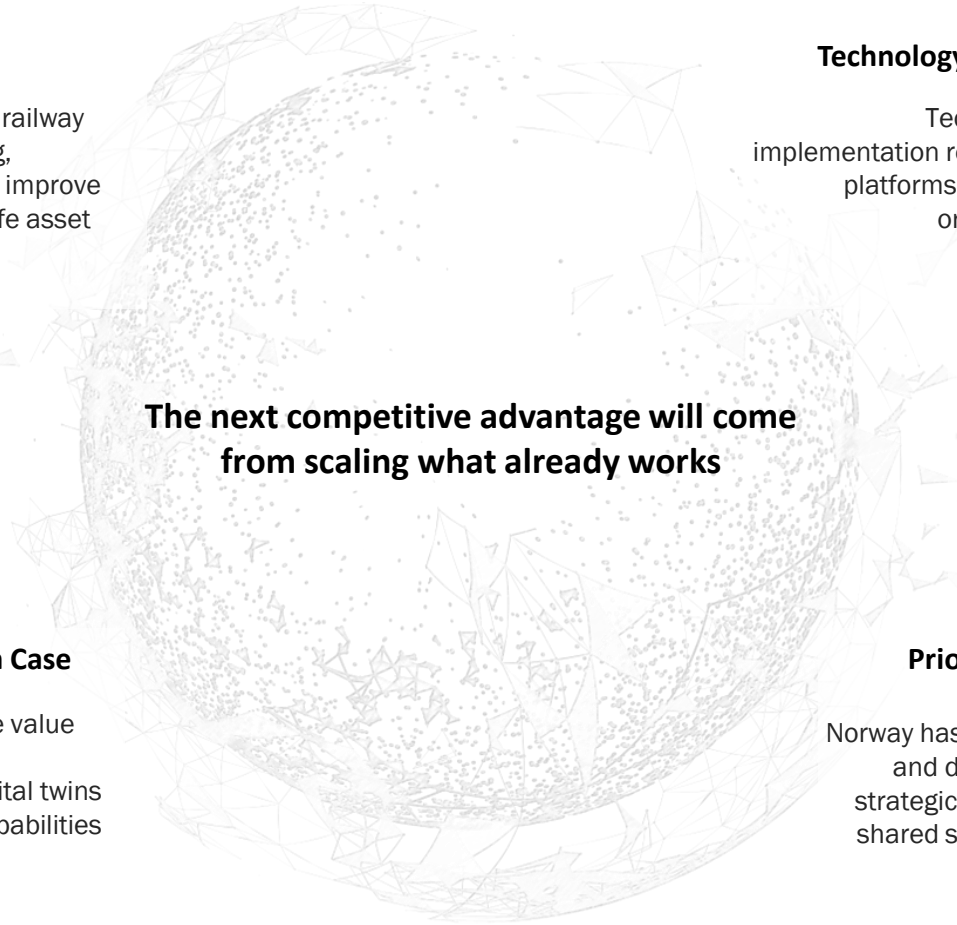
Digital twins provide an integrated, continuously updated view of railway assets, systems and operations. By enabling real-time monitoring, simulation, and predictive decision-making, they can significantly improve reliability, operational efficiency, capacity utilisation, and whole-life asset performance.

The Economic Opportunity Is Significant

Digital and AI-enabled railway applications could generate substantial global value, USD 13–22 billion annually, through lower life cycle costs, increased asset availability, more efficient testing, and improved network capacity. For passengers and freight customers, this means greater punctuality, fewer disruptions, and a more reliable and predictable transport service.

Predictive Maintenance Presents the Strongest Near-Term Case

Predictive maintenance offers the clearest pathway to immediate value by reducing unplanned failures, extending asset life, improving availability, and optimising maintenance resources. Life cycle digital twins and digital testing provide the supporting data and simulation capabilities required to scale these benefits.



The next competitive advantage will come from scaling what already works

Technology Must Be Supported by Strong Digital Foundations

Technology alone will not deliver transformation. Successful implementation requires high-quality and standardised data, interoperable platforms, validated models, robust cybersecurity, clear ownership, organisational capability, and confidence in digital outputs.

Realising Value Requires a Coordinated Sector

Progress must be advanced across four interconnected dimensions: data and standards, technology platforms, applications and use cases, and organisation and governance. Alignment across these dimensions is essential to move from isolated innovation to scalable, sector-wide value creation.

Priority Must Shift from Innovation to Implementation

Norway has established a strong portfolio of digital railway initiatives and demonstrates technological and innovation capability. The strategic priority is now to scale what works into solutions through shared standards, clearer governance, stronger coordination, and more effective implementation mechanisms.

Glossary

AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BIM	Building Information Modelling
CAPEX	Capital Expenditure
CBM	Condition-Based Maintenance
C-DAS	Connected Driver Advisory System
CMMS	Computerised Maintenance Management System
DAC	Digital Automatic Coupler
DIM	Digital Infrastructure Model
EN	European Standard
ERA	European Union Agency for Railways
ERJU	Europe's Rail Joint Undertaking
ERTMS	European Rail Traffic Management System
ESG	Environmental, Social and Governance
ETCS	European Train Control System
FE	Finite Element
FRMCS	Future Railway Mobile Communication System
GDP	Gross Domestic Product
GIS	Geographic Information System
HIL	Hardware-in-the-Loop
IAM4RAIL	Intelligent Asset Management for Rail
IFC	Industry Foundation Classes
IoT	Internet of Things
KPI	Key Performance Indicator
LiDAR	Light Detection and Ranging
LLM	Large Language Model
NTP	National Transport Plan
OPEX	Operating Expenditure
R2DATO	Rail-to-Digital Automated Train Operation
ROI	Return on Investment
RSM	Rail System Model
SIL	Software-in-the-Loop
SRIA	Strategic Research and Innovation Agenda
TCMS	Train Control and Monitoring System
TIOS-A	Traffic/Terminal Information and Optimisation System
TOGIRO	Norwegian railway digital management and planning tool
TSI	Technical Specification for Interoperability
UIC	International Union of Railways
VR	Virtual Reality

A **knowledge report** on digital twin technology for **rail**

This report provides a strategic assessment of how digital twins can create value across the railway life cycle. It combines technology fundamentals, five promising railway applications, global lessons on adoption, and an assessment of current initiatives and implementation pathways in the Norwegian railway sector.

Commissioned by the Norwegian Railway Directorate and Europe's Rail, the report is primarily intended for railway decision-makers and stakeholders responsible for strategy, innovation, investment, and implementation. While the recommendations are tailored to Norway, many of the findings are relevant to railway organisations in other countries and regions.

The report moves from concept to implementation. It first establishes the fundamentals and evaluates five digital twin applications, before examining global adoption practices and the Norwegian railway landscape. It concludes with WSP's strategic recommendations for scaling successful initiatives and translating digital innovation into operational and sector-wide value.

Content

01

Digital Twin Fundamentals & Methodology

Introduces Digital Twins with core principles and dimensions. Report methodology is presented. This section sets the foundation for understanding how Digital Twins can transform and enhance railway management and operations.

02

Five promising Digital Twins applications in Rail

Presents promising concepts on how Digital Twin technology can enhance the railway sector. Examines five high-potential applications across the railway life cycle and assesses their contribution across six pillars.

03

Global Best Practices in Railway Digital Twin Adoption

Provides an overview of cross-cutting topics in Digital Twin adoption. Addresses a wide range of topics based on global lessons learned, crucial to understand and identify opportunities and threats that arise with increased adoption of digital twin in railway or industry operations.

04

Norwegian railway landscape - Digital twin initiatives and use cases

Provides an overview of the Norwegian railway sector, highlighting key public and private stakeholders. Outlines opportunities and challenges in meeting strategic and operational goals and offers insight into the local context shaping the adoption and implementation of Digital Twin technologies.

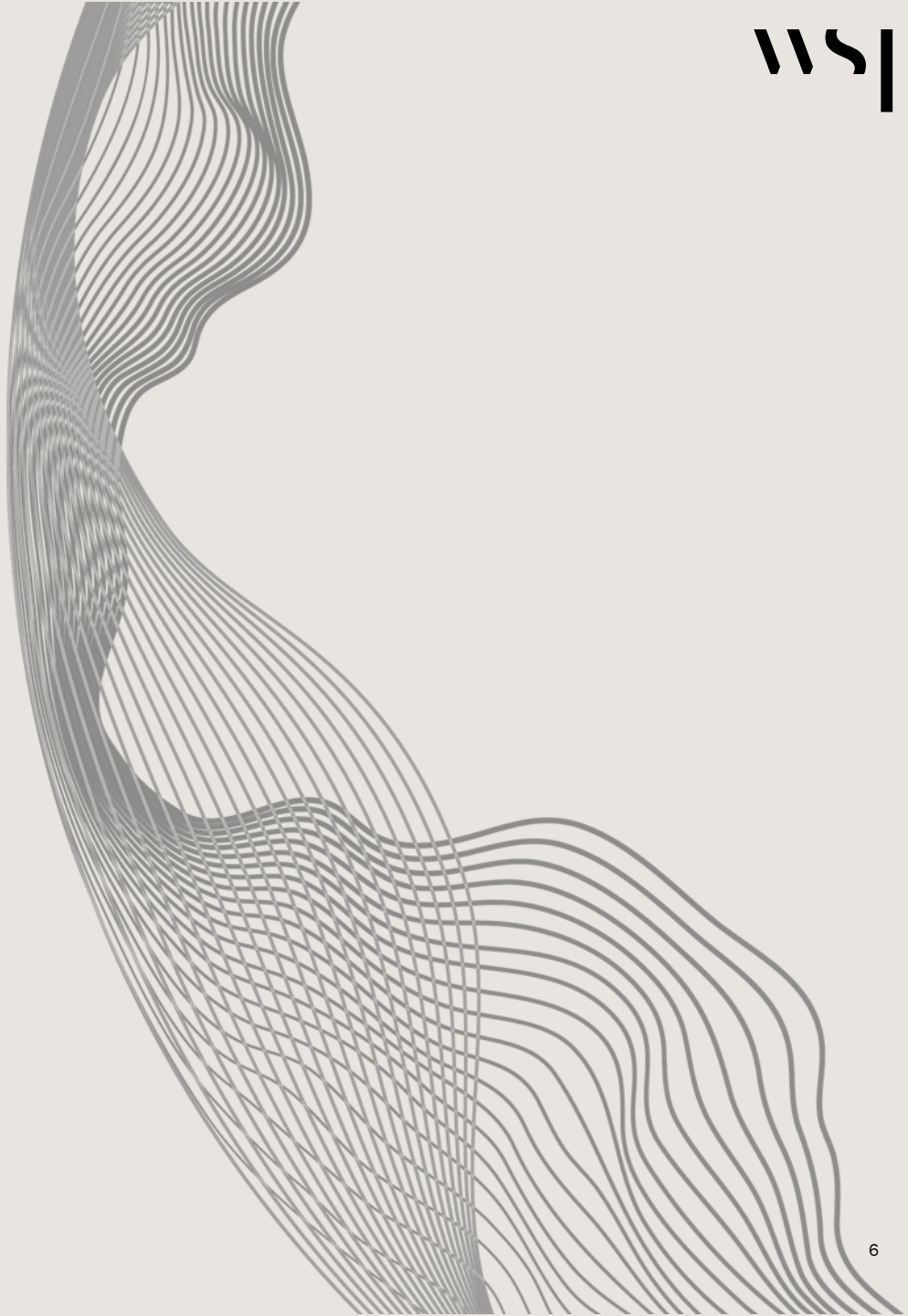
05

Strategic Assessment & Recommendations

Bridges key insights from technology use cases, value creation, adoption strategies and experience from the Norwegian railway sector. Provides actionable recommendations to enhance management and operations and align with railway sector goals.

01

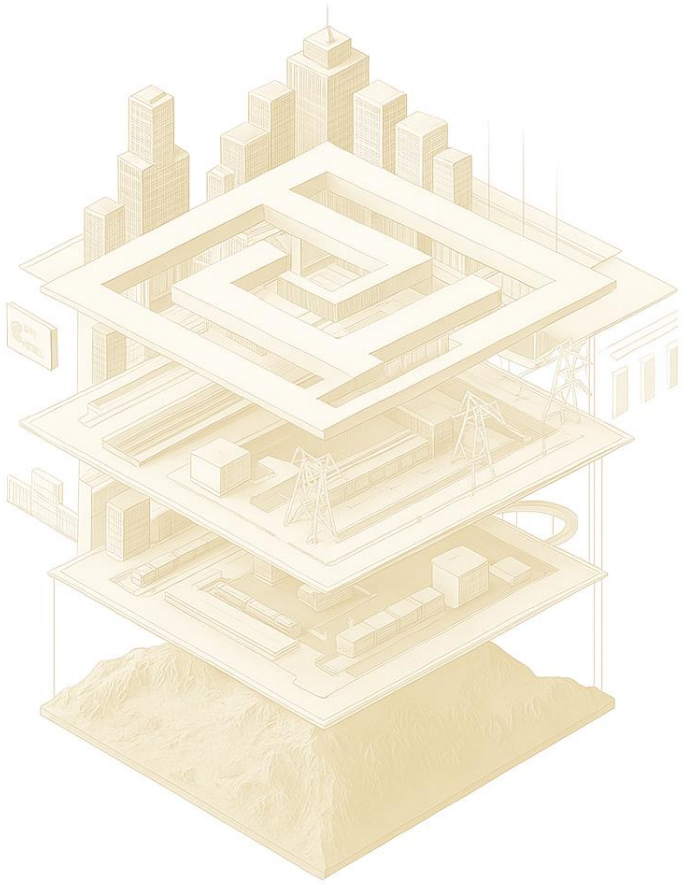
Digital Twin Fundamentals & Methodology



What defines a digital twin?

Digital twins can support monitoring, simulation, prediction and informed decision-making across the life cycle.

> A digital twin is a digital representation of a target entity, connected through data so that the digital and real-world states converge at an appropriate rate of synchronisation
>
> Digital twin definition, ISO/IEC 30173:2023.



Synchronisation
Uses connected data to maintain alignment between the digital representation and its real-world counterpart. Updates may range from periodic to near-real-time, depending on the use case.

Simulation and Prediction
Can combine data and models to test scenarios, analyse behaviour and predict future performance. More advanced applications may recommend or initiate actions, while human oversight may remain necessary.

Fit-for-purpose representation
Represents the entity at a level of detail appropriate to the purpose, decision and life cycle stage. A visual or 3D interface may be useful, but is not required.

Integration
Integrates relevant data, models and contextual information from multiple sources to provide a coherent representation of the target entity.

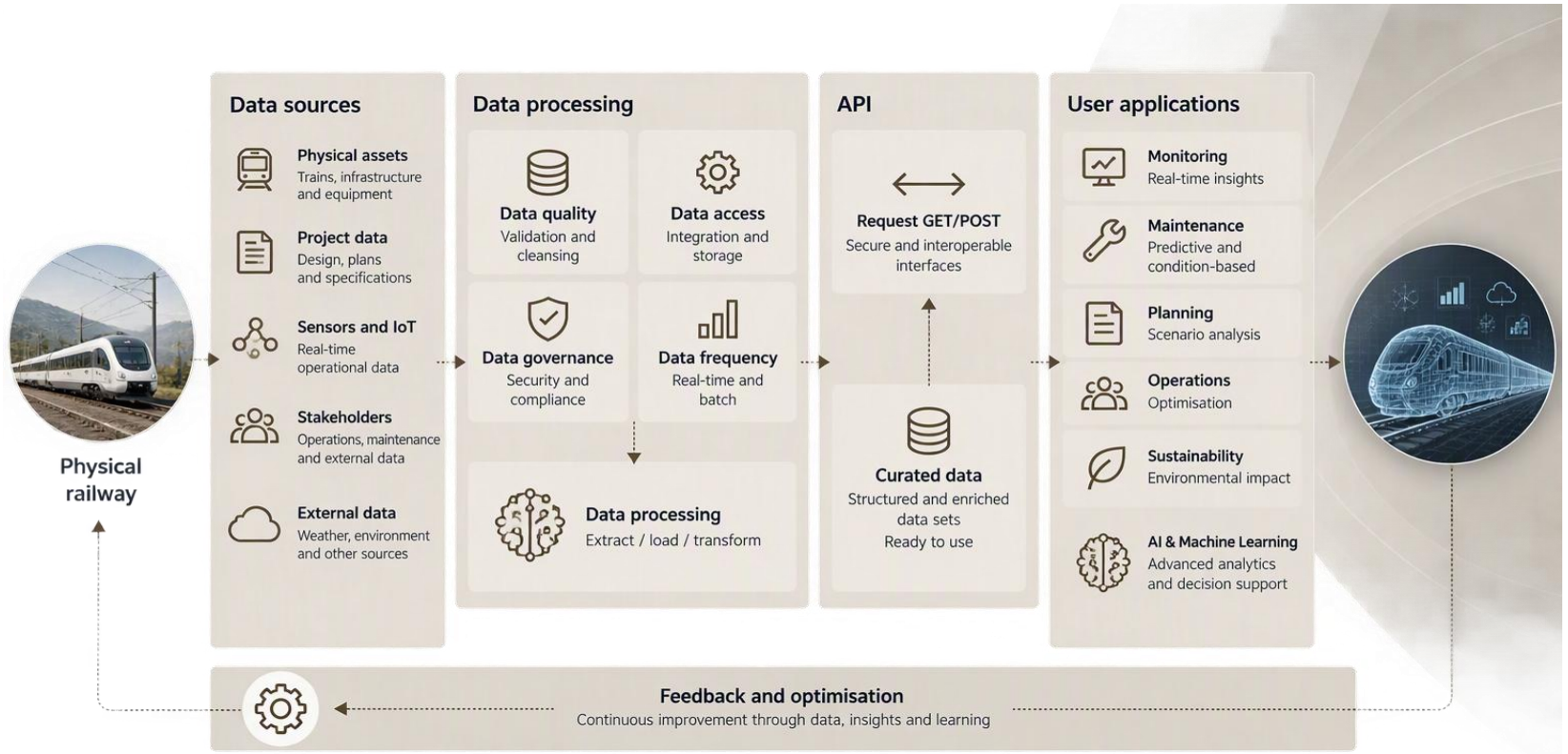
Digital model	Digital shadow	Digital twin
→Manually updated representation	→Automatically updated through one-way data flow	→Synchronised and capable of supporting feedback

Sources:
1. Definition: ISO/IEC 30173:2023, Digital twin: Concepts and terminology
2. WSP (2024): Teknologitrender for jernbanesektoren
3. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications

Digital twin behind the scenes

A digital twin connects the physical railway with data sources, processing capabilities and user applications, as shown in the illustration on the right. Data is collected, governed and transformed into structured information that supports monitoring, simulation, prediction and decision-making. Insights and recommended actions are fed back to the physical railway, creating a continuous cycle of learning and optimisation. The degree of synchronisation, feedback and decision-support capability determines whether a solution is categorised as a digital model, digital shadow or digital twin.

Digital twin behind the scenes, illustrated. AI-generated image based on a concept and prompt developed by WSP



Sources:
1. Definition: ISO/IEC 30173:2023, Digital twin: Concepts and terminology
2. WSP (2024): Teknologitrender for jernbanesektoren
3. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications

Technology innovations and improvements enable more advanced digital twins and industry applications

Technology is advancing at an accelerating pace, creating new opportunities for more capable and scalable digital twin applications. As illustrated in the digital twin architecture, these capabilities depend on a range of enabling technologies. Among the most important for the railway sector are the Internet of Things, intelligent transport systems, data infrastructure, and artificial intelligence.

In 2024, WSP Norway identified four tech megatrends and 17 tech trends with particular relevance for the railway sector (WSP, 2024). Connectivity, digitalisation, automation, and electrification all influence the development and application of digital twins. Among the identified trends, several stand out as particularly important:

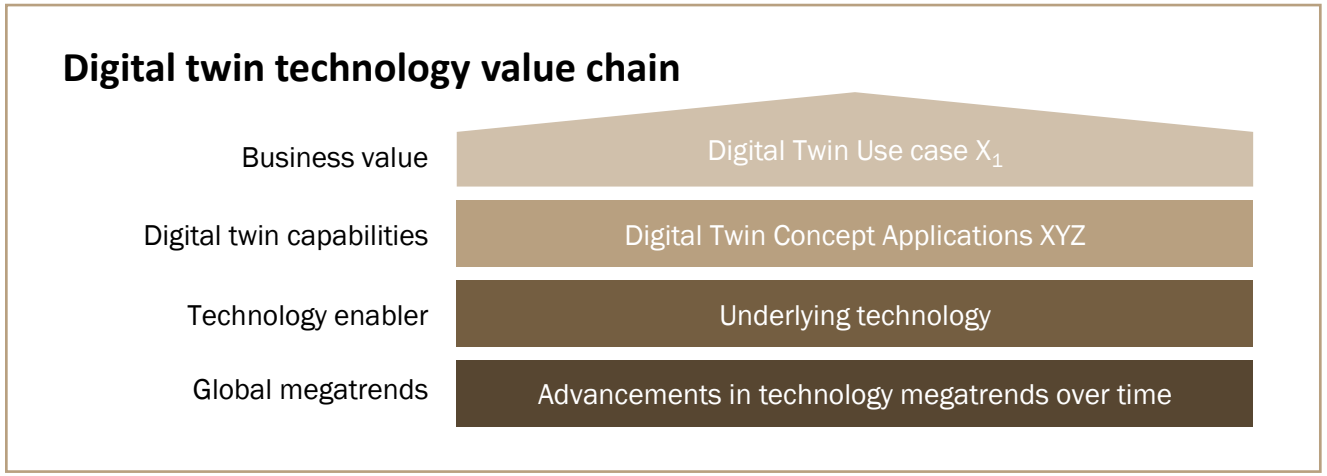
IoT and intelligent transport systems: Provide continuous real-time data, improving the accuracy, responsiveness, and predictive capability of digital twins.

Data infrastructure: Enables faster processing, richer models, scalable environments, and higher-quality digital twin applications.

Artificial intelligence: Enhances analytics, prediction, automation, and decision support.

Together, these technologies strengthen the capabilities of digital twins and enable more advanced railway applications. The key strategic challenge is no longer whether technology will mature, but where and when to invest to maximise value creation.

Digital twin technology value chain. WSP



1. WSP (2024): Teknologitrender for jernbanesektoren
2. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress
3. Sarp et al. (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
4. Ghaboura et al. (2023): Digital Twin for Railway: A Comprehensive Survey
5. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications

Report Methodology

The report uses a four-stage approach: collecting and analysing data, mapping key trends, evaluating and prioritising initiatives, and providing strategic recommendations. This structured process ensures informed decisions, focuses on high-impact opportunities, and delivers a roadmap for digital transformation in the Norwegian railway sector.

Methodology				
1 **Data Collection & Analysis** Collect data from stakeholders, projects, and global benchmarks. Analyse technical and strategic aspects to identify gaps and opportunities.	**2** **Use Cases Discovery** Identify and map emerging trends in Digital Twin technology and railway innovation. Highlight areas with potential for value creation and transformation.	**3** **Evaluation & Categorisation** Evaluate trends for feasibility, relevance, and impact. Prioritise initiatives that deliver the greatest strategic value.	**4** **Strategic Assessment & Recommendations** Develop actionable strategies and a roadmap for implementation. Address governance, technology integration, and collaboration.	Stages
Provides a comprehensive knowledge base and identifies gaps in current practices, enabling informed decision-making.	Creates a clear picture of future opportunities and challenges, ensuring alignment with global and regional developments.	Focuses resources on high-impact areas, reducing risk and accelerating implementation of transformative solutions.	Delivers a roadmap for digital transformation, enhancing key metrics for improved railway performance.	Impact

Note: The value assessments and maturity assessments presented in this report are based on literature reviews, expert input, international benchmarking, and professional judgement. Results should be interpreted as directional rather than predictive.

Value Assessment Pillars

The scoring framework ensures each digital twin application is evaluated across critical dimensions of performance and strategic value. It provides a structured approach to compare initiatives, prioritise those with the greatest impact, and support informed decision-making for long-term success, customer satisfaction and value for money.

Pillars

Productivity

Evaluates the impact on operational efficiency, resource utilisation, and overall performance improvement.

Cost Efficiency

Assesses potential for reducing operational and maintenance costs while optimising life cycle costs and asset utilisation.

Reliability

Measures reliability, resilience, and ability to maintain consistent performance under varying conditions.

Sustainability

Examines contribution to environmental goals, energy efficiency, and long-term sustainable practices.

Scalability

Determines how easily the solution can be expanded across systems, assets, and future technologies.

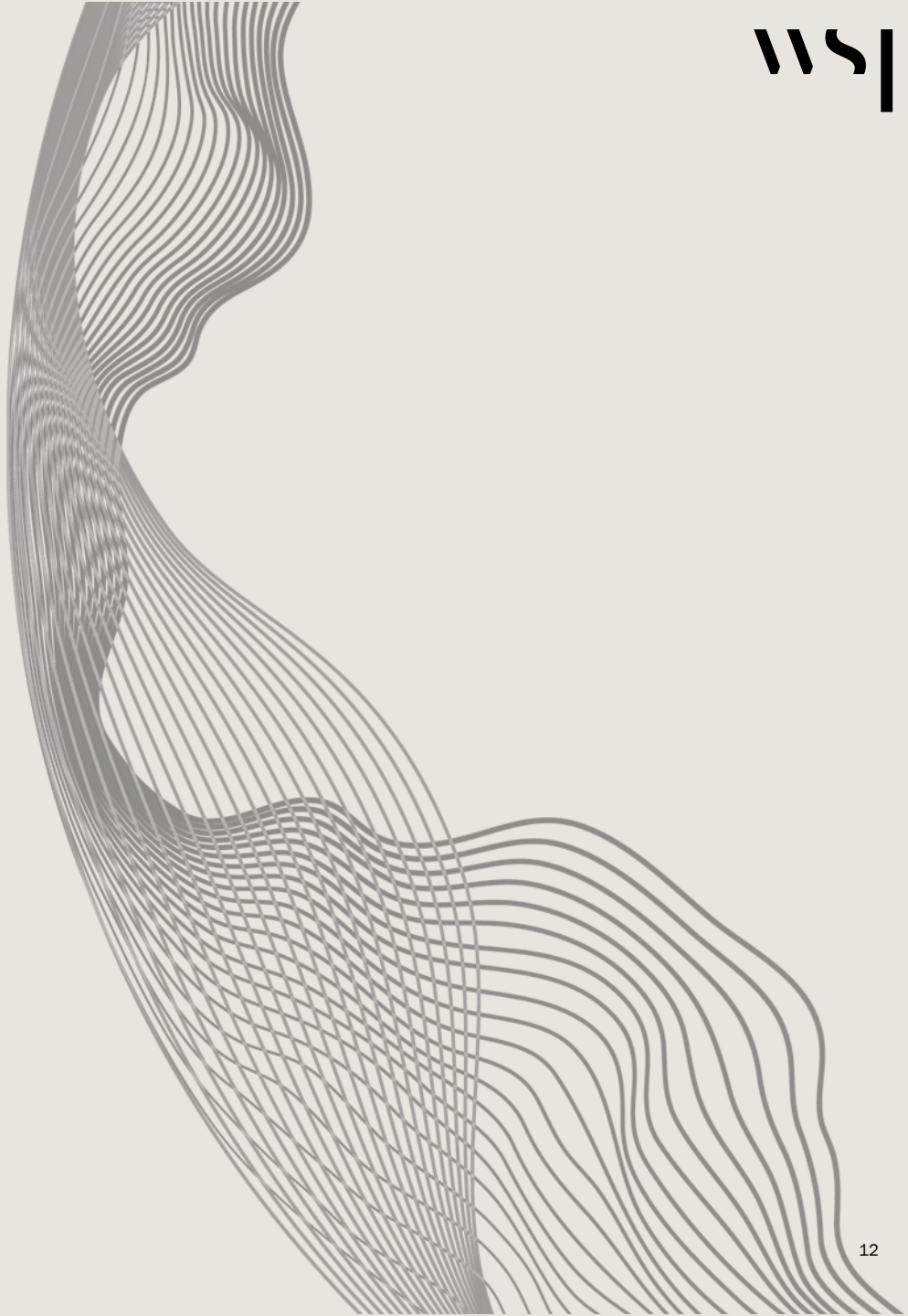
Safety & Security

Assesses the potential to reduce accidents, failures, harm and security threats.

Note: For each of the pillars there is a set of sub-pillars that give the scoring for each value. The following sub-pillars have been used in the assessment. 1) Productivity (automation level, Throughput Improvement, ROI Timeframe (ROI)), 2) Cost efficiency (Annual Cost Savings, Asset/resource Utilisation, and CAPEX, OPEX reduction), 3) Safety & Security (Risk reduction, Cybersecurity and infrastructure protection, Safety assurance and validation), 4) Sustainability (Energy Efficiency, Emission reduction, Asset life expansion) 5) Scalability (Performance at Scale, Modularity, Scaling cost-effectiveness), 6) Reliability (Operational performance and uptime, Operational trust, Resilience and robustness)

02

Five Promising Digital Twin Railway Applications



Five Promising Digital Twin Railway Applications

The five applications represent high-potential opportunities to improve railway across value dimensions such as efficiency, reliability, and life cycle performance.

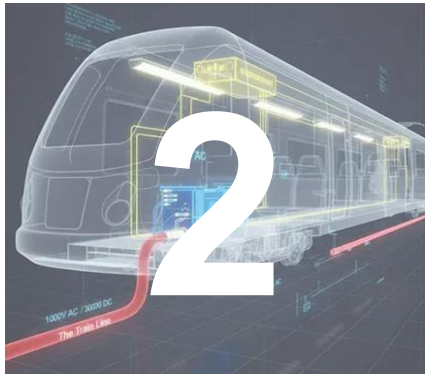
Life cycle Digital Twin

Enhancing BIM models throughout the asset life-cycle



Railway Digital Testing

Digital testing of railway rolling stock and assets



Rail Predictive Maintenance

Providing predictive maintenance with railway condition monitoring



AI & Process Automation in Rail

Enhancing digital twins with automation and AI agents

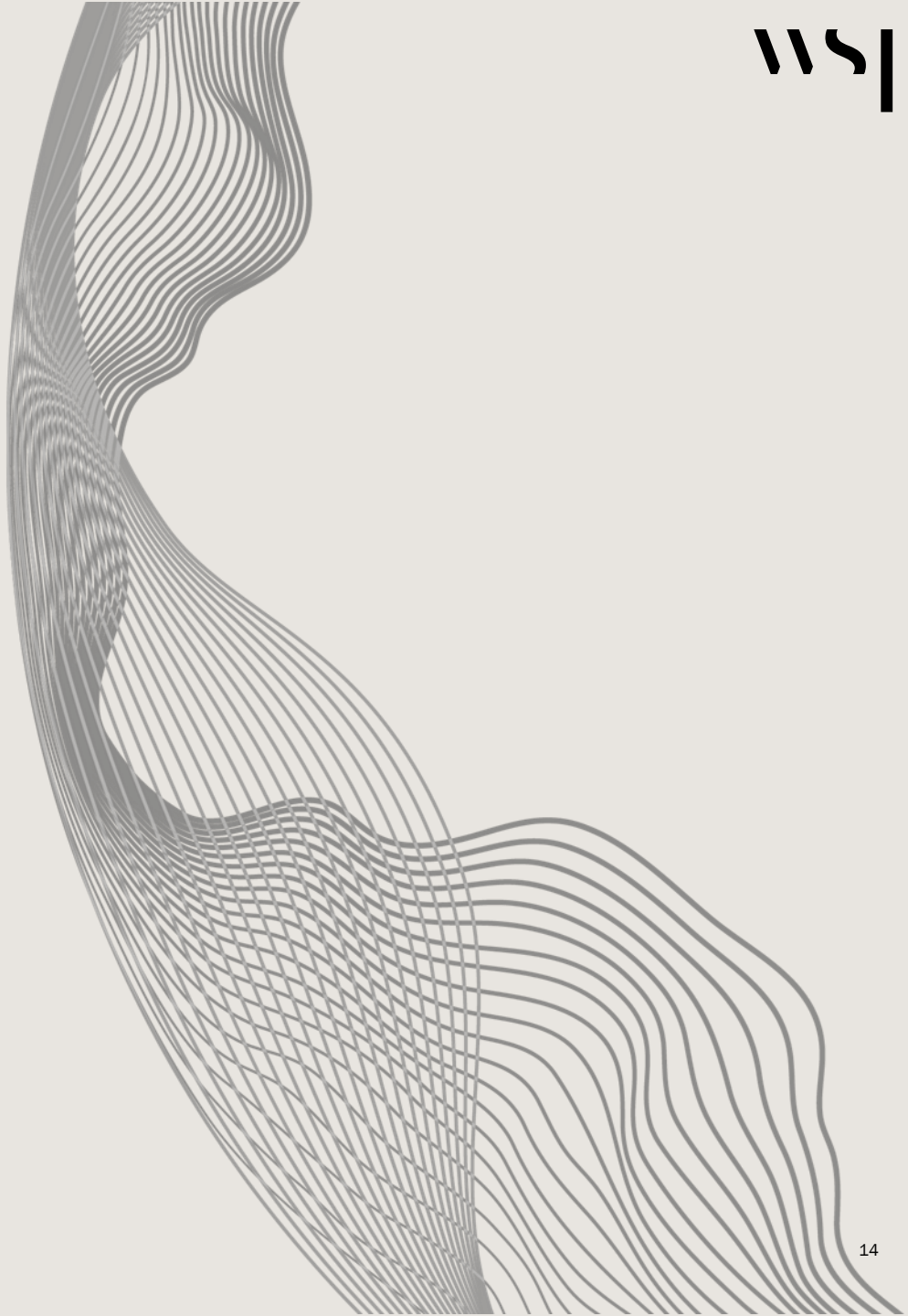


Digital Training and Operations

Training and performing operations in digital environments



02.1
Life Cycle Digital Twin



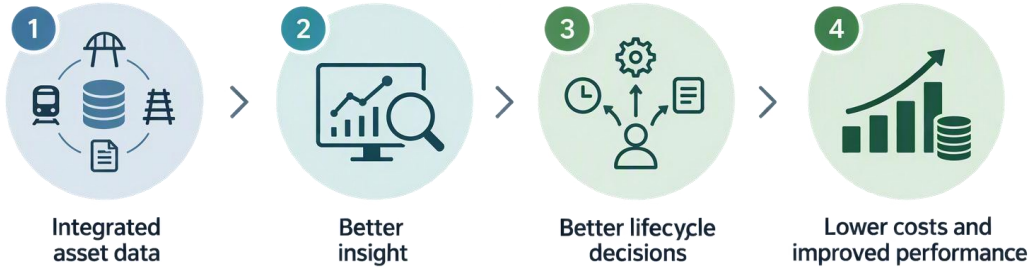
Introduction and why it matters

Life cycle digital twins, derived from enhanced BIM models and multiple datasets, represent the backbone of digital transformation in the railway sector – providing the structured, high-quality data environment that enables productivity gains across the full life cycle of railway assets.

A life cycle digital twin integrates geometry, engineering information, specifications, operational performance, and historical data into a coherent structure. This improves design quality, streamlines commissioning, and enables applications such as condition monitoring, predictive maintenance, simulation, and automation.

With standardised and scalable models, organisations can apply digital twins across asset types, from lines and stations to tunnels, bridges, and rolling stock. Accurate data provides better insight into asset health, performance, risks, and renewal needs, supporting informed maintenance and investment decisions while enabling future upgrades and long-term efficiencies.

BIM is now a mature foundation for railway planning, design, and delivery. Extending datasets through visual interfaces improves collaboration between humans and machines, although visualisation is not a prerequisite for a life cycle digital twin. Data can be represented through different interfaces for humans, AI, and machines depending on the task.



How Life Cycle Digital Twins Create Value. AI illustrated. WSP

1. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle
2. WSP Global (2026): *life cycle digital twins*
3. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
4. Europe's Rail (2026). *FP1-MOTIONAL*
5. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications

Latest development and use cases

Advances in sensor integration, standardised data environments and simulation technologies now make it possible to unify planning data, construction records, operational insights, and maintenance history in one continuous digital thread. These developments provide a stronger basis for predictive analytics, automated inspections, and asset-level decision-making – significantly improving efficiency in an asset-heavy railway environment.

Design & Constructability Optimisation
Life-cycle digital twins allow engineers to simulate construction phasing, test design alternatives, perform ESG or other tests, detect mistakes early, and ensure that optimal solutions and as-built conditions feed directly into the operational twin. This reduces rework, strengthens coordination, and shortens construction timelines.

Modularisation, Pre-fabrication & Automated Production
Standardised and richly structured models enable consistent data handover to suppliers and contractors, supporting modular build strategies, off-site fabrication, and automated assembly processes or 3D printing – significantly reducing waste, cost, and on-site risk.

Digital Network-Scale Planning
High-fidelity digital twins give planners an authoritative reference for capacity analysis, operational simulations, and scenario testing. They form the digital baseline used for strategic timetables, service design, and long-term infrastructure development.

Condition Monitoring as the Foundation for Proactive Asset Management
Condition monitoring within life-cycle digital twins enables continuous insight into the real condition and performance of railway assets by combining sensor data, operational records, and historical trends in one coherent data environment. This shifts asset management from reactive inspection to proactive, data-driven decisions, improving reliability, safety, and long-term cost efficiency across the entire asset life cycle. In railways, this approach is well proven: for a long time, sensors for detecting wheel flats and other rolling-stock defects have been in operation. More recently, advanced inspection portals equipped with sensors, lidar, and camera systems have expanded the ability to detect a wide range of anomalies, generating high-quality data that supports continuous optimisation and informed maintenance decisions. Feeding these data into digital twins has the potential to enable even richer and more proactive decision-making.

Foundation for Digital Twin applications
Life-cycle twins serve as the backbone for future digital twin concepts outlined in the following chapters addressing digital testing, predictive maintenance, automation and digital training and operations.

1. WSP Norway (2026): Digital twin use cases in Norwegian transport sector
2. Digital Twin Consortium (2021) Infrastructure Digital Twin Maturity: A Model for Measuring Progress
3. ERRAC (2020) Rail Strategic Research and Innovation Agenda
4. WSP Global (2026): *life cycle digital twins*
5. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
6. Europe's Rail (2026). *FP1-MOTIONAL*
7. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications
8. WSP, Dassault systems and Deutsche Bahn (2023): Enterprise Asset Management and Digitalization of Rail Systems

Life cycle Digital Twin Score

Overall score

7,5 / 10

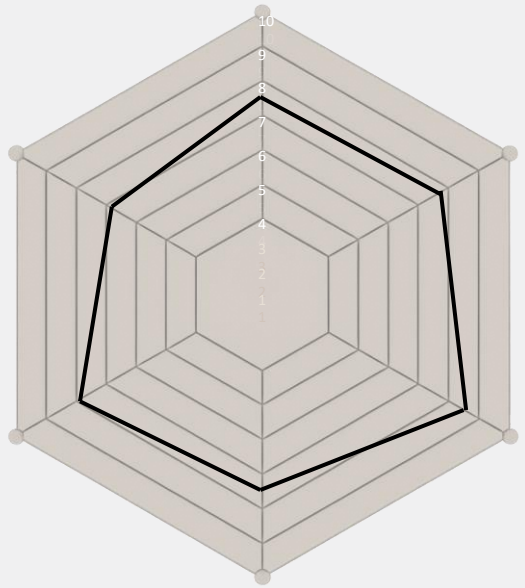
Expected value creation from implementation in railway

Life-cycle digital twins create value by providing a consistent, high-quality digital backbone across planning, construction, operation, and maintenance. By integrating data, models, and operational insight over time, they enable better asset decisions, improved reliability, reduced life cycle cost, and a scalable foundation for advanced applications such as predictive maintenance, simulation, and automation.

Key Uncertainties

- **Model sharing and governance:** Stakeholders still lack clear rules for model ownership, access rights, version control and liability across the asset life cycle.
- **Usability and stakeholder needs:** Different stakeholders need different outputs. Solutions that fail to accommodate these needs and fit operational workflows risk low adoption and eventual abandonment.
- **Data quality and interoperability:** Maintaining reliable, consistent data across the asset life cycle and enabling different systems to exchange and use it remain challenges.
- **Delivery and long-term value:** Large, complex, project-driven solutions can limit flexibility and weaken the link between system design, ongoing software management and operational value. This risks costly solutions that see little use.

Scores above 5 indicate an *improvement* from current railway system*



7,7/10

Productivity

Integrated asset and operational data automate monitoring and issue detection, helping teams plan services and investments more efficiently

6,9/10

Safety & Security

Better operational planning can support safer operations, but cybersecurity risks require effective safeguards

7,6/10

Cost Efficiency

Less rework, predictive maintenance and better asset decisions can reduce costs across the asset life cycle

6,8/10

Scalability

The technology can scale, but legacy systems, heterogeneous environments and asset digitisation increase the cost of expansion

8,7/10

Reliability

Earlier issue detection and better outage planning help reduce disruption and enable faster operational response

7,5/10

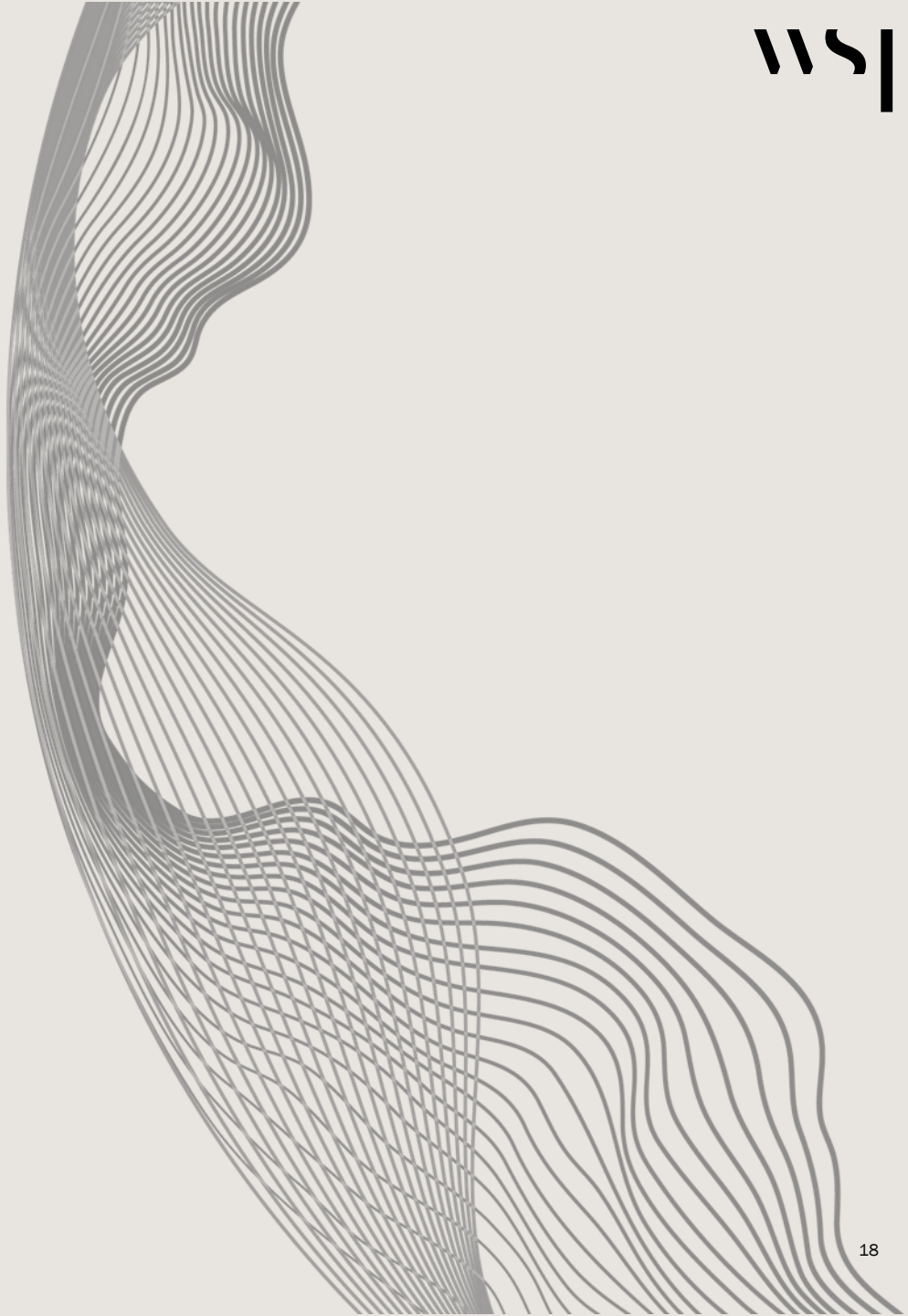
Sustainability

Better planning and asset life assessment support lower emissions and more energy-efficient construction and maintenance

1. WSP Norway (2026): Digital twin use cases in Norwegian transport sector
2. Digital Twin Consortium (2021) Infrastructure Digital Twin Maturity: A Model for Measuring Progress
3. ERRAC (2020) Rail Strategic Research and Innovation Agenda
4. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
5. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications
6. WSP, Dassault Systems and Deutsche Bahn (2023): Enterprise Asset Management and Digitalization of Rail Systems

Note: *Railway systems do vary across geographies and GDP-levels. The benchmark (spiderweb above) is done across digital twin applications in comparison with a continuation of a typical European railway system with its pros and cons.

02.2
Railway Digital Testing



Introduction and why it matters

Digital testing uses validated digital twins and simulation environments to verify railway performance earlier in the development cycle, reduce physical testing, and safely analyse scenarios that are difficult or impossible to reproduce on track. Digital testing can also be used throughout the life cycle for investigating incidents or improving performance. Virtual testing can accelerate certification, subject to acceptance of simulation-based evidence. This can strengthen design robustness, safety assurance, and long-term system optimisation.

Digital testing delivers significant benefits across both the design and authorisation phases of railway assets, while also creating substantial value during operation. In the pre-operational phase, it enables earlier verification, allowing non-compliances to be identified while design changes are still feasible – reducing cost, improving safety, and avoiding the time-critical constraints of on-track testing. During operation, digital testing is easier to perform as it does not require physical access to rolling stock or infrastructure and allows operating conditions to be varied more extensively, resulting in larger and more robust datasets for analysis and continuous improvement. While not everything can be tested digitally and real-asset testing will always remain necessary, the scope of physical testing, such as testing under multiple loading conditions, can often be reduced, making digital testing a major advancement across the asset life cycle.

Digital testing environments typically rely on multi-body simulation, FE analysis, and software- and hardware-in-the-loop (SIL/HIL) techniques that focus on individual aspects. Life-cycle digital twins enable these approaches to be connected within a more unified ecosystem, strengthening digital testing by providing a consistent, validated data and model foundation that links simulations with real-world data and feedback throughout design, authorisation, and operation. Our value assessment assumes that simulation-based evidence is accepted alongside physical testing.



1. Ricardo (2026): Virtual testing & Digital twins. Presentation
2. Vermeij (2025): Making virtual railway testing a reality. Ricardo/WSP
3. Vermeij (2025): Opportunities and challenges in sharing digital twins. Ricardo/WSP
4. Global Railway Review (2023): How digital twins drive better outcomes in rail
5. Bentley (2020): Digital Twins Drive Better Outcomes across the Rail Asset life cycle
6. Biblus (2024): Digital Twin Railway: The Future of Railway Management

Latest development and use cases

Digital testing is becoming a key enabler for safer and more efficient railway operations. By validating designs early, it reduces redesign loops and accelerates deployment. As rail systems grow more complex, virtual environments offer a strong foundation for testing, simulation, and performance validation. Regulators are beginning to accept virtual certification evidence, allowing validated simulation models to replace or reduce costly on-track tests, thus extending today's testing framework.

Multi-Body Dynamics for Running Behaviour
Simulates vehicle–track interaction to assess stability, derailment safety, comfort, wheel–rail forces, wear, and degraded conditions. Validated models support EN 14363 compliance and can reduce physical testing, although new train designs still require full test campaigns.

Digital Testing of Rolling Stock and Components
Virtual environments support dynamic validation of bogies, brakes, couplers, suspensions, and running gear. They enable early fault detection, design optimisation, and automated scenario testing — reducing redesign loops, increasing accuracy, and lowering overall project cost. Examples are pantograph simulations according to EN 50318 and a CEN Technical Specification for brake performance simulation is under development.

Being able to test early (with digital testing) reduces the risk of design delays, shortening the design process and gives required on track tests better time tolerance.

Software- and Hardware-in-the-Loop (SIL/HIL) Validation
Complex onboard systems (ATO, ETCS/ATP, braking logic, control software) are tested in digital testbeds that replicate real-time operational conditions. This improves reliability, supports regression testing, and makes it possible to validate edge-case behaviours that are unsafe or impractical to verify on track.

Structural & Fatigue Testing Using FE-Based Digital Twins
Finite-element models simulate structural loads, fatigue behaviour, crack propagation and component durability across the vehicle life cycle. FE digital twins allow verification against standards such as EN12663 and EN13749 and reduce the need for physical tests.

Scenario-Based Operational Testing
Digital twins simulate operational edge cases such as emergency braking, degraded-mode operations, timetable conflicts, and system-to-system interactions. These simulations support training, improve resilience and enhance reliability. Simulations can also cover situations that are hard to replicate in real life due to cost, capacity constraints, or complexity.

1. WSP (2026): Digital twin use cases in Norwegian transport sector
2. Ricardo (2026): Virtual testing & Digital twins. Presentation
3. Vermeij (2025): Making virtual railway testing a reality. Ricardo/WSP
4. Vermeij (2025): Opportunities and challenges in sharing digital twins. Ricardo/WSP
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6. Bentley (2020): Digital Twins Drive Better Outcomes across the Rail Asset life cycle
7. Biblus (2024): Digital Twin Railway: The Future of Railway Management
8. Virtual Vehicle (2026): Virtual Validation for Certification of Railway Vehicle Braking Performance
9. Ghaboura et al. (2023): Digital Twin for Railway: A Comprehensive Survey. IEEE Vol. 11

Railway Digital Testing Score

Overall score

7,7 / 10

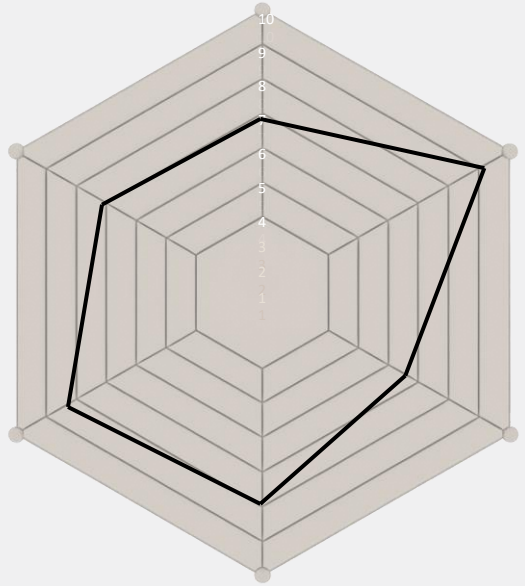
Expected value creation from implementation in railway

Digital testing enabled by digital twins creates value by shifting verification and learning earlier in the life cycle, where changes are faster, safer, and less costly. By complementing physical testing with validated simulations, railways can reduce rework, minimise project delays and improve quality across design, authorisation, and operations. The result is a more efficient and moreover highly scalable testing regime that strengthens railway reliability.

Key Uncertainties

- **Model sharing and governance:** Stakeholders still lack clear rules for model ownership, access, version control and liability across the asset life cycle.
- **Regulatory acceptance and timing:** Standards and safety frameworks do not yet fully define when simulations can replace physical tests or what mix of testing different loading scenarios and edge cases require. The pace of regulatory change adds uncertainty about when wider adoption will be possible.
- **Model validation and testing quality:** Quality varies in both physical and digital testing. Credible digital results depend on rigorous model validation.

Scores above 5 indicate an *improvement* from current railway system*



6,9/10

Productivity

Automation improves testing efficiency, but complex technical requirements and strict safety standards still require expert input

7/10

Safety & Security

Digital testing reduces risks associated with physical tests. Further operational safety gains are possible, although current testing already ensures high safety levels

9,2/10

Cost Efficiency

Reducing the need for costly on-track testing offers substantial savings

8,4/10

Scalability

Modular models support reuse across assets, making digital testing easier to scale

6,6/10

Reliability

More extensive testing, including edge cases, can improve reliability. Gains are modest because existing testing already provides strong assurance

8/10

Sustainability

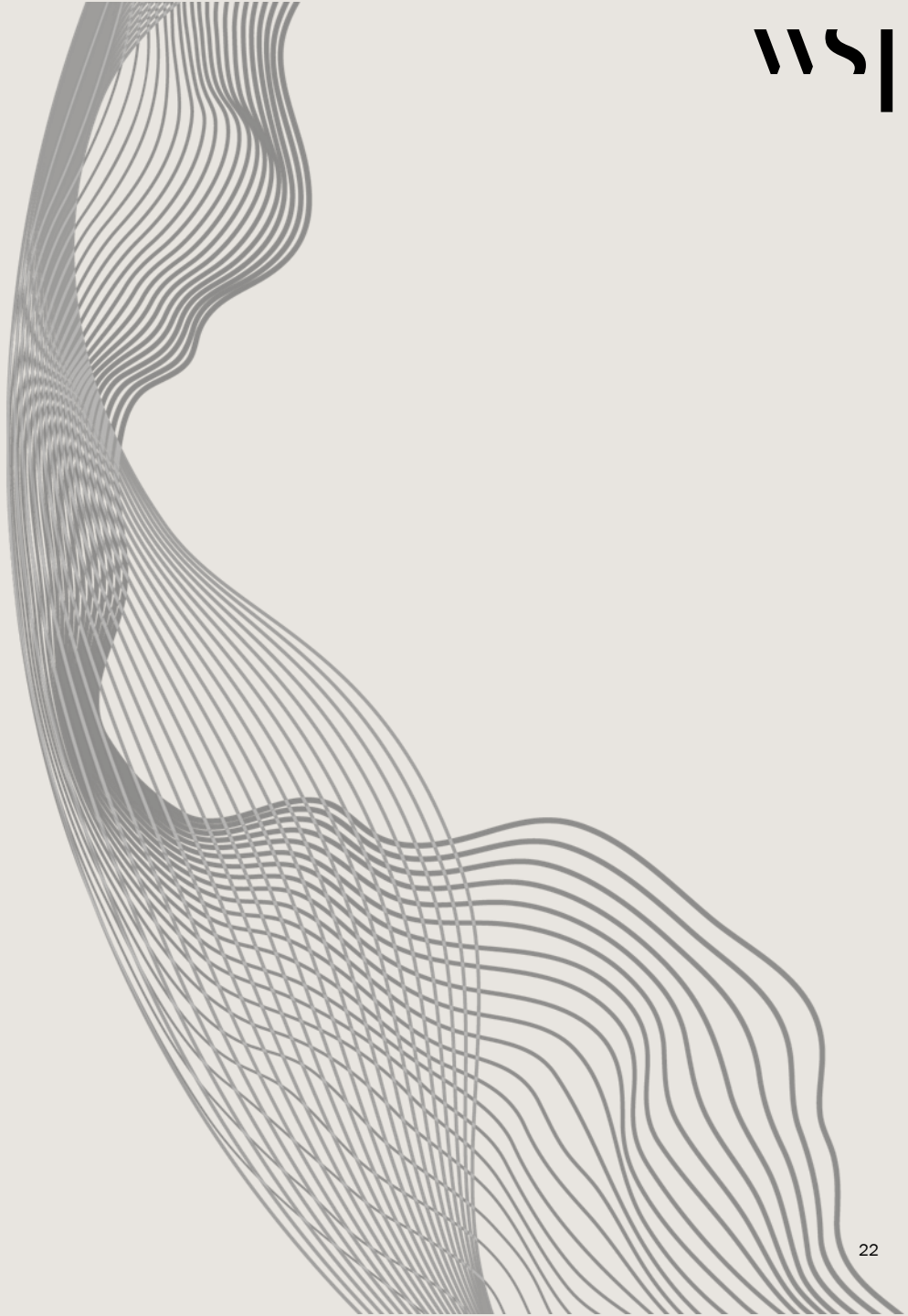
Less physical testing on tracks reduces the energy needed for testing

1. Ricardo (2025). Opportunities and challenges in sharing railway digital twins. Industry Insights
2. European Union Agency for Railways (ERA). Technical Specifications for Interoperability (TSIs)
3. European Committee for Standardization (CEN). Railway applications – Guidance for the use of simulations to demonstrate compliance with technical and regulatory requirements (CEN/TR 17833:2022)
4. Railway Track & Structures (2024). Using Digital Twin Simulations to Reduce Derailment Risks.
5. International Union of Railways (UIC) (2026). Railway Digital Modelling and Rail System Model (RSM).

Note: *Railway systems do vary across geographies and GDP-levels. The benchmark (spiderweb above) is done across digital twin applications in comparison with a continuation of a typical European railway system with its pros and cons.

02.3

Rail Predictive Maintenance



Introduction and why it matters

Predictive maintenance represents one of the clearest pathways for digital twins to deliver measurable value in an asset-heavy railway sector. By combining sensor data, condition monitoring, behaviour modelling, historic records, and automated analytics, operators gain a dynamic view of asset health and deterioration mechanisms — enabling smarter decision-making and long-term productivity gains.

Rail Predictive Maintenance uses data-driven monitoring, sensors, and digital twin insights to identify early signs of degradation across critical railway assets. Instead of relying on periodic inspections or reactive interventions, predictive maintenance enables operators to anticipate failures before they occur — improving safety, reliability, passenger confidence and operational stability across an asset-heavy network. This approach significantly reduces downtime, optimises maintenance planning, and creates a more resilient railway system aligned with long-term life cycle management.

Monitoring systems of railway assets are already in place for many railway assets, explained in the previous chapter on life-cycle digital twins. On such systems condition-based or predictive maintenance can be done. High asset intensity makes early detection essential. Digital twins, supported by real-time condition data, create a stronger analytical foundation for predicting failures before they occur. This reduces disruptions, stabilises timetables, and improves passenger experience, while also scaling effectively across tracks, rolling stock, catenary, switches, bridges, and tunnels. For assets it's valuable to be able to test/predict both infrastructure degradation based on frequent use over time and high-impact edge cases with potentially serious outcomes.



Photo: Kristian Helgeland

1. WSP, Dassault systems and Deutsche Bahn (2023): Delivering Intelligent Integrated Digital Rail Systems and Operations & Maintenance
2. Bentley (2025): Advancing rail through infrastructure intelligence
3. Rocha & Gonçalves (2024): Digital Twins as Enablers of Predictive Maintenance in Rail Transport Services
4. ERRAC (2020): Rail Strategic Research and Innovation Agenda (SRIA)
5. WSP (2026): Leading the Transportation Industry's Digital Transformation

Latest development and use cases

Rail predictive maintenance is rapidly advancing with the use of digital twins, AI-driven sensor systems, edge-AI processing, and multi-source data fusion, enabling earlier detection of wheel, track, and component degradation and significantly reducing unplanned failures. Digital twins enable an environment where condition monitoring data can be stored, analysed and appropriate actions can be performed.

Digital twins enhance asset health monitoring and prediction of events
Digital Twins fuse geometry measurements, vibrations, sensor data, and environmental conditions to forecast wear, deformation, and risk zones – enabling targeted interventions before failures affect traffic. Some basic versions of such systems have been used for years – while digital twins enable richer and more intelligent information and decision making.

An ongoing effort to collect data cheaper and more frequent is to apply cameras on trains to gather information and monitor infrastructure. Recently drones have become cheaper and ongoing pilots in railway and examples from other industries show how drones will become an important part in future surveying of objects – especially difficult assets to reach such rural assets, as bridges, steep hills replacing expensive manual monitoring. More frequent data from such areas can be used to predict snowfall, rockfall or flood that can be a danger for both passengers and assets. Limiting disruptions from such events will increase uptime and secure access. This is particularly important for railway which usually do not have detour options.

Rolling stock condition prediction
Component-level digital shadows (doors, compressors, braking systems, bogies, by use of TCMS data for instance) identify anomalies early and support condition-based maintenance, reducing workshop time and ensuring higher fleet availability.

Switches and signalling equipment
Trend-based monitoring of point machines, interlockings, and switch devices detects deviations from “normal curves,” supporting automated fault classification and maintenance prioritisation.

Structural and civil infrastructure assessment
Bridges, tunnels, and drainage systems can be monitored with lidar, accelerometers, and environmental sensors. Digital twins identify hidden risks, track long-term deterioration, and optimise renewal decisions.

Integrated network-wide prediction models
By combining data from trains, infrastructure inspection train, and trackside sensors, Digital twins provide a unified view of future maintenance needs. This supports smoother capacity planning, fewer disruptions, and overall operational stability.

1. WSP, Dassault systems and Deutsche Bahn (2023): Delivering Intelligent Integrated Digital Rail Systems and Operations & Maintenance
2. WSP (2026): Digital twin use cases in Norwegian transport sector
3. Onyeka et al. (2025): Machine learning-augmented digital twin systems for predictive maintenance in high-speed rail networks
4. Mhalla et al. (2026): Digital Twins and Railway Networks Maintenance: A Partnership for Efficiency and Safety
5. Railway news (2025): Mirroring Reality: The Power of Digital Twins in Rail
6. Ricardo (2026): PUPIL Revolutionise Your Track Management

Rail Predictive Maintenance Score

Overall score

7,8 / 10

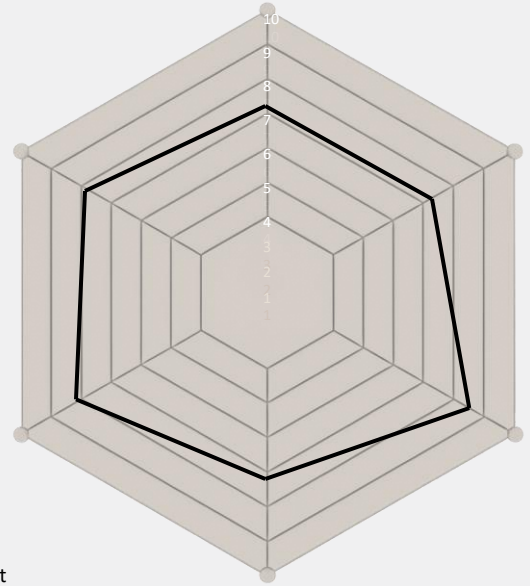
Expected value creation from implementation in railway

Rail predictive maintenance creates value by shifting maintenance from reactive interventions to proactive, data-driven decisions. By combining condition monitoring, historical data, and analytics, it reduces unplanned failures, improves reliability and safety, and extends asset life. The result is more stable operations, lower life cycle costs, and better use of maintenance resources across the network.

Key Uncertainties

- **Data availability and quality:** Many older assets lack sensors and require costly retrofitting. Incomplete and inconsistent maintenance records further limit the data available for reliable condition assessments and predictive models.
- **Stakeholder coordination and governance:** Fragmented ownership, differing responsibilities and incentives complicate investment priorities and data sharing. Rules for model ownership, access, version control and liability also remain unclear.
- **Technical interoperability and standardisation:** Diverse asset types and limited integration through APIs make it difficult to connect models and systems and apply common standards across the railway network.

Scores above 5 indicate an *improvement* from current railway system*



7,3/10
Productivity
Automation improves maintenance efficiency, but strict regulations and safety standards still require expert judgement

7,9/10
Safety & Security
Better monitoring and targeted maintenance reduce safety risks, while greater digital dependence introduces vulnerabilities that require safeguards

7,4/10
Cost Efficiency
Longer asset life can defer replacement investment. Maintenance remains necessary, so cost savings are partial

8,2/10
Scalability
Economies of scale support wider deployment, but costs and savings depend on local conditions and asset characteristics

8,8/10
Reliability
Predictive maintenance reduces unplanned failures and improves railway uptime by enabling maintenance before faults disrupt operations

7,3/10
Sustainability
Predictive maintenance extends asset life. Energy-efficiency benefits are also expected, but their extent is less certain

1. WSP, Dassault systems and Deutsche Bahn (2023): Delivering Intelligent Integrated Digital Rail Systems and Operations & Maintenance
2. Bentley (2025): Advancing rail through infrastructure intelligence
3. Rocha & Gonçalves (2024): Digital Twins as Enablers of Predictive Maintenance in Rail Transport Services
4. ERRAC (2020): Rail Strategic Research and Innovation Agenda (SRIA)
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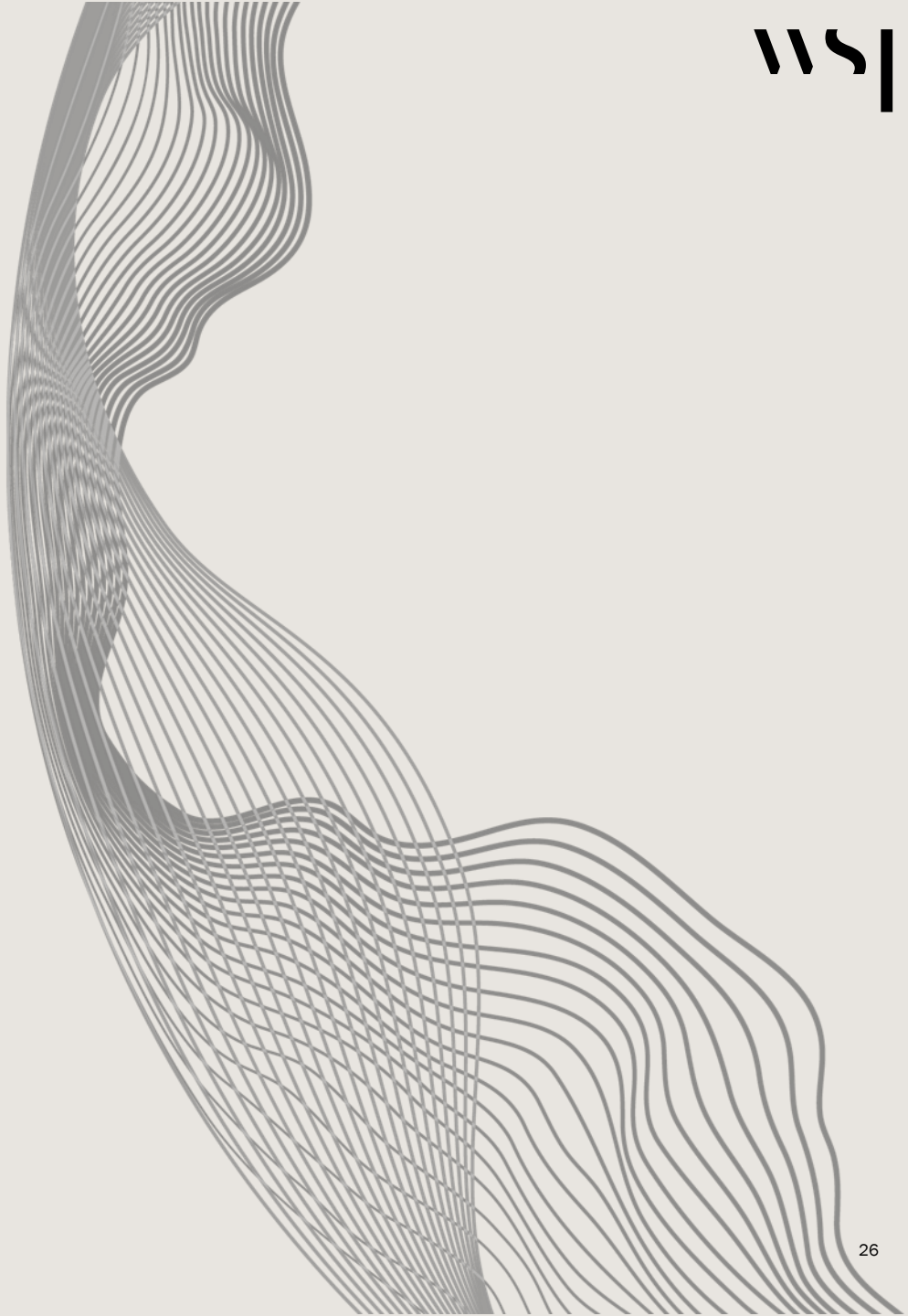
02.4

AI & Process Automation in rail

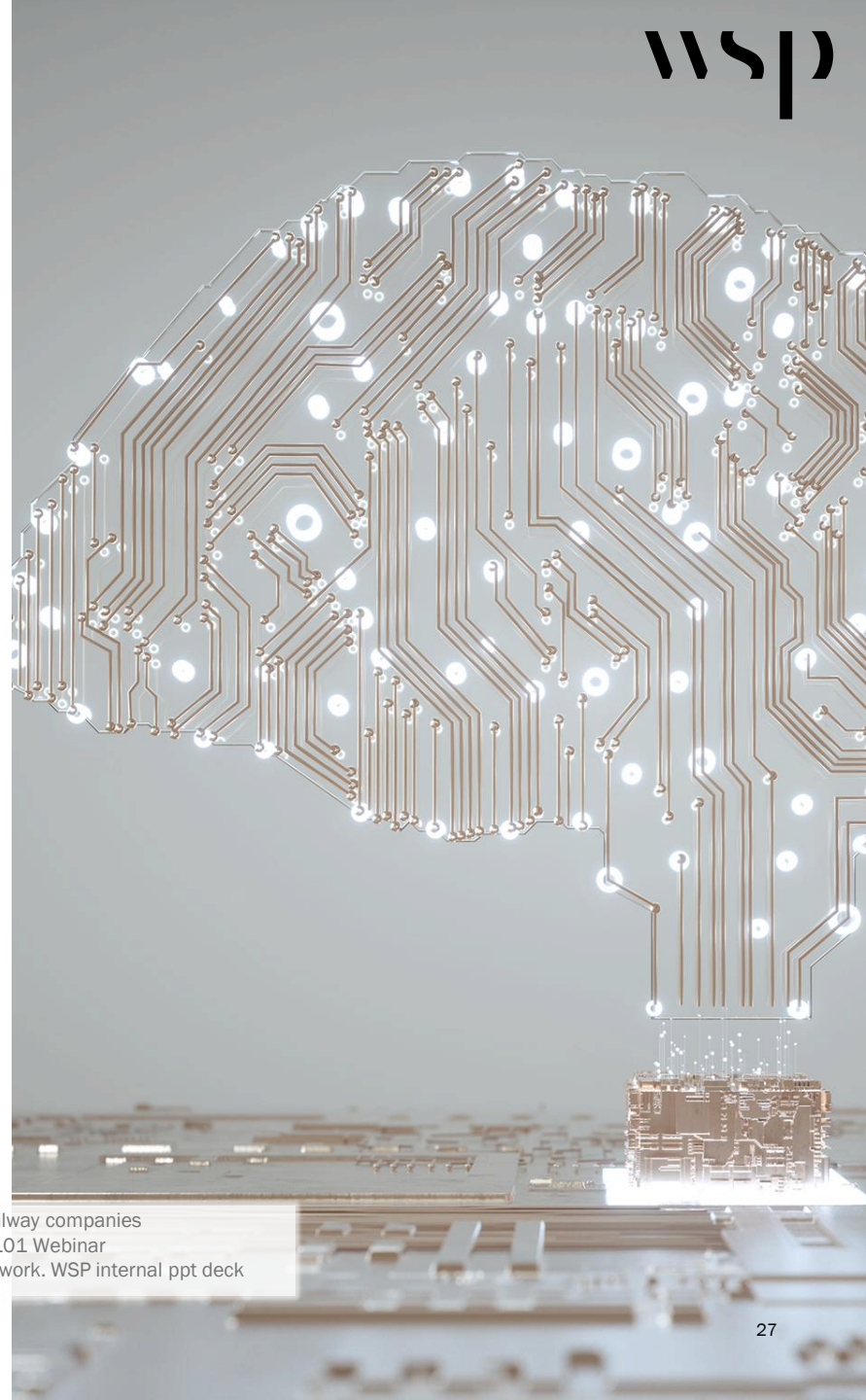


Introduction and why it matters

AI agents are advancing automation, decision support and simulation across sectors, including railways. They draw on operational data, including logs and behavioural patterns, to support staff and automate tasks. Integrating these capabilities into digital twin systems can strengthen decision-making and enable actions within the feedback loop.

As railway systems become more data-rich and operationally complex, digital twins and AI agents provide new ways to support decision-making, optimise operations, and automate routine tasks. Automation and AI can support both the upstream flow of data in a digital twin and the downstream feedback loop, where AI agents can translate insights into support for decisions and actions. AI agents can themselves function as digital twins when they represent a specific real-world entity or process and maintain a synchronised connection with it. AI agents use insights to replicate routine decision-making, support human expertise, and help reduce costs and bottlenecks across the railway value chain.

At the same time, AI-enabled automation is expanding across railway operations. Robotised inspection tools and autonomous platforms are increasingly used for track monitoring, tunnel scanning, and rolling-stock assessment, improving safety and inspection efficiency. Advances in supervised autonomy and self-driving capabilities are enhancing operations, and can contribute to more reliable traffic flow, better punctuality, and improved energy efficiency. In stations, yards, and freight terminals, intelligent systems support more efficient shunting, loading, and resource planning.



1. Ricardo/WSP (2026): Virtual Testing & Digital Twin Applications
2. Sarp et al. (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
3. Stephens (2024): Revolutionising Railways: The Power of AI and Digital Twins. LinkedIn article
4. Spread (2025): French National Railways meets spread: How digital twins and unified product data redefine generations.
5. UIC (2024): The journey toward AI-enabled railway companies
6. Global Railway Review (2024): Digital Twins 101 Webinar
7. WSP Digital Engineering & Automation Framework. WSP internal ppt deck

Latest development and use cases

Together AI agents, digital twins, robotics and sensing technologies, can extend automation and decision support across the railway value chain. These technologies can support and automate routine administrative processes as well as more complex operational tasks, improving efficiency, decision-making, and overall system performance.

Advanced Human-Task Simulation
AI agents capable of performing dispatcher routines, control-room decision chains, or maintenance planning workflows are being deployed to streamline processes, reduce bottlenecks, and improve overall resilience in day-to-day operations.

Robotised Infrastructure Inspection and field operations
Autonomous drones, crawlers, and robotic platforms perform continuous inspections of tracks, tunnels, and structures, reducing the need for manual track access and increasing the frequency and precision of condition monitoring. Increasingly robots and autonomous systems will be able to perform field operations and actions required, enabled by digital twin closed-loop automation, with or without supervision by humans.

Self-Driving and ATO-Supported Train Operations and DAC
Advances in sensor fusion, train control algorithms, and digital twin validation support higher levels of Automatic Train Operation, enabling smoother driving profiles, improved punctuality, and safer handling of degraded conditions. Advanced digital environments are essential for technologies like Digital Automatic Coupler (DAC), enabling increased automation and more efficient terminal and shunting operations.

Automated Terminal and Yard Operations
Semi-autonomous cranes, automated shunting systems, automatic coupling and digital coordination tools streamline freight handling, reduce dwell times, and enhance safety through optimised movement of rolling stock and loading units.

This shows that digital twins are the backbone for real-time decision support and automated operations (how digital twins can be used for validation and training purposes will be covered in the next chapter). Together, these developments demonstrate how AI and process automation are becoming a powerful catalyst for improved efficiency, stronger resilience, and more adaptive railway operations.

Automated Documentation and Compliance Processes
Rail organisations are applying AI agents to automate reporting, documentation validation, fleet data processing, and regulatory compliance tasks – significantly reducing administrative workload and human error.

1. WSP (2026): Digital twin use cases in Norwegian transport sector
2. Mhalla and Dutielleul (2026): Digital Twins and Railway Networks Maintenance: A Partnership for Efficiency and Safety
3. Francisco, Verdecia-Peña and Alonso (2026): A Survey of AI-Enabled Predictive Maintenance for Railway Infrastructure: Models, Data Sources, and Research Challenges
4. WSP Global (2025). Transportation AI Field Guide.
5. WSP Digital & Technology: Digital Twin Victoria Presentation (2023)

AI & Process Automation in Rail Score

Overall score

7,4 / 10

Expected value creation from implementation in railway

AI & Process Automation delivers strong value potential for the railway sector, driven by high productivity and cost-efficiency gains from automating administrative and operational workflows. Key constraints relate to safety, trust, and cybersecurity, requiring robust validation, governance, and human oversight. While technically scalable, organisational fragmentation and interoperability challenges limit full system-wide rollout. Overall, AI Process Automation through digital twins is a high-impact enabling capability.

Key Uncertainties

- **Trust in automated outputs:** Reliance on AI recommendations remains limited, requiring human oversight and gradual confidence-building through validation and operational use.
- **Cybersecurity exposure:** Increased connectivity and automation expand the attack surface, making robust cybersecurity measures and governance essential.
- **Validation and assurance:** Clear methods for validating AI behaviour, explaining outputs, and assuring consistent performance are still evolving.
- **Interoperability and integration:** Fragmented IT landscapes, weak APIs, and legacy systems complicate end-to-end automation across organisations.
- **Organisational adoption:** Differences in roles, responsibilities, incentives, and maturity across stakeholders slow scaling and system-wide rollout.

Scores above 5 indicate an *improvement* from current railway system*

9/10

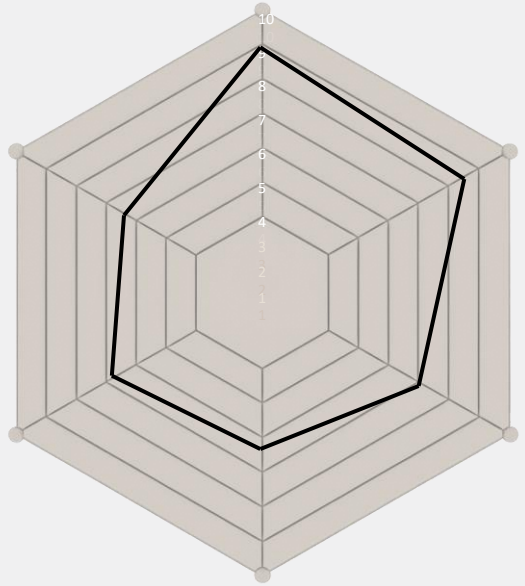
Productivity

Delivers strong productivity gains by automating repetitive workflows, accelerating throughput across planning, coordination, and documentation, and enabling faster decision-making.

6,3/10

Safety & Security

Improves safety through better risk identification, but overall impact is constrained by cybersecurity exposure and evolving trust in automated outputs



8,7/10

Cost Efficiency

Is driven by significant reductions in manual effort and rework and lower operating costs, while capital impacts remain indirect but positive through better asset utilisation.

6,8/10

Scalability

The technology scales well from a technical perspective due to its software-based nature, but organisational fragmentation, interoperability challenges, and scaling costs limit system-wide rollout

7,2/10

Reliability

AI process automation enhances consistency and operational performance, yet full reliability depends on human oversight, trust in outputs, and robustness of data and system integrations.

6,4/10

Sustainability

Sustainability benefits are mainly indirect, achieved through reduced travel, fewer interventions, and improved planning.

1. Ricardo/WSP (2026): Virtual Testing & Digital Twin Applications
2. Sarp et al. (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
3. Stephens (2024): Revolutionising Railways: The Power of AI and Digital Twins. LinkedIn article
4. Spread (2025): French National Railways meets spread: How digital twins and unified product data redefine generations.
5. UIC (2024): The journey toward AI-enabled railway companies
6. Global Railway Review (2024): Digital Twins 101 Webinar
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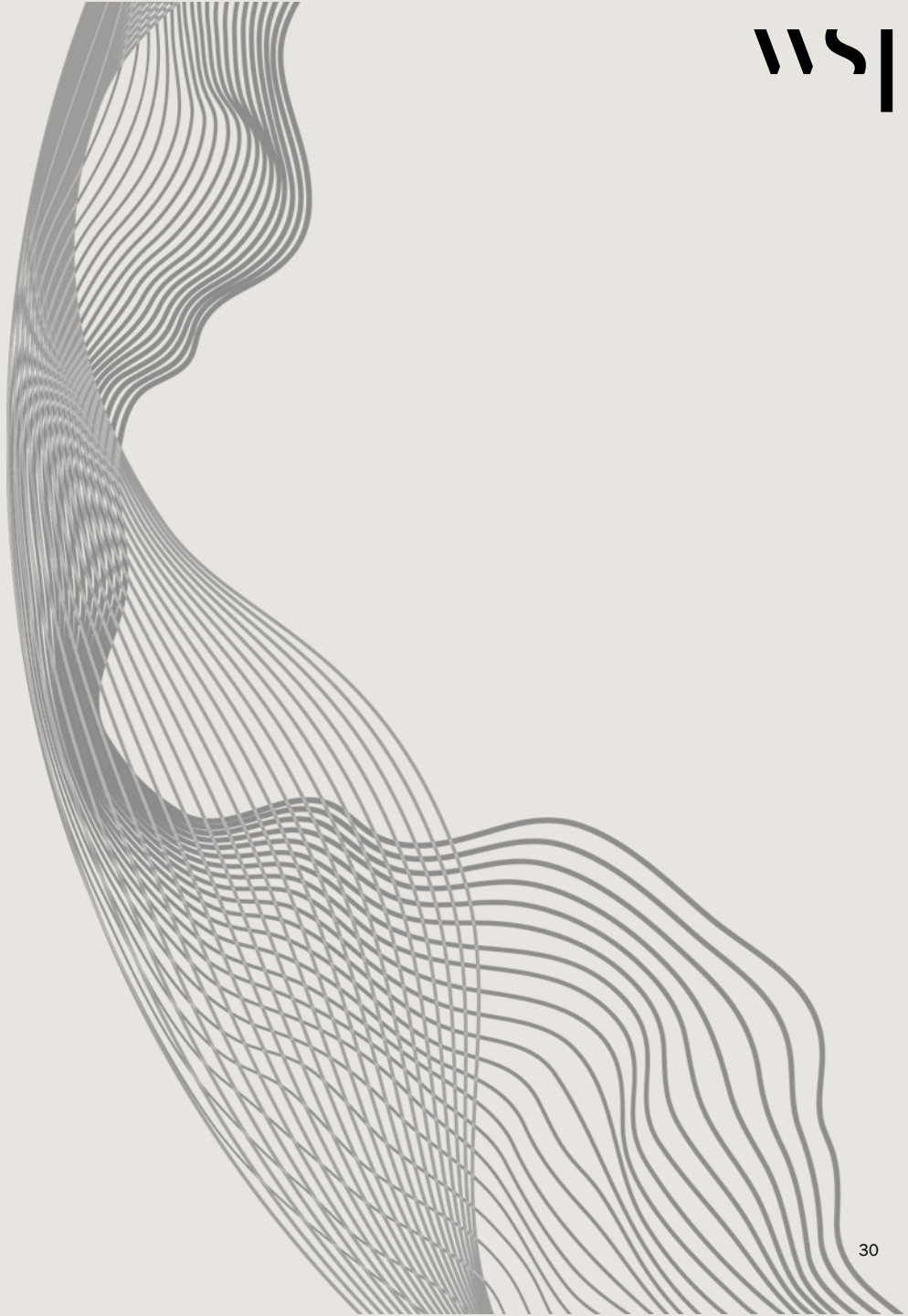
02.5

Digital Training and Operations



Introduction and why it matters

Training and operations in digital environments is becoming a key enabler for capability, safety, and efficiency in the railway sector, particularly as the interaction between humans and increasingly intelligent systems grows and becomes increasingly mutually dependent. On a journey to more automated systems and processes, interaction between humans and machines will increasingly be part of training and operations.

As railway systems become more complex and digitally driven, immersive platforms, such as simulators, virtual environments, and interactive digital twins, enable personnel to work alongside automated systems, decision-support tools, and AI-enabled processes in a safe and controlled setting. This allows staff to practice critical tasks, understand system behaviour, and build trust in automation without disrupting traffic or exposing people or assets to risk.

Digital training environments make it possible to simulate realistic operating conditions, emergency scenarios, and rare but high-impact events that are difficult to reproduce in real life, strengthening preparedness and supporting faster competence development.

As simulations, AI-assisted assessments, and digital twin technologies mature, they provide richer feedback on both human performance and system interactions, improving decision-support and creating a scalable foundation for future workforce development.

Training in digital environments is therefore not only a modern learning tool, but an essential component of resilient, efficient, and future-ready railway operations where humans and machines increasingly operate as an integrated system.



1. WSP (2025): Emergency training in digital environments, Cross River Rail, Australia.
2. Mhalla and Dutielleul (2026): Digital Twins and Railway Networks Maintenance: A Partnership for Efficiency and Safety
3. Railways Magazine (2025): Virtual Railways: How Simulation Helps Train the Next Generation of Rail Workers
4. Ricci M. et al. (2025): Exploiting Immersive Virtual Reality for Maintenance Training of Freight Trains
5. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications
6. Smart Spatial Blog (2025): 18 Use Cases of Operational Digital Twins in Railways
7. LinkedIn: Baderao, Pranali (2025): Driving the Future: How VR and AR are Revolutionizing Train Training Simulators
8. Nexefy (2026): Immersive VR Rail Industry Training Solutions

Latest development and use cases

Digital training and operations is rapidly evolving as immersive technologies mature, providing railway organisations with safer, more efficient, and highly scalable ways to build competence, rehearse and perform digital operations. Modern simulation tools combine realistic digital twins, advanced visualisation, and AI-driven assessment methods to replicate complex railway environments with unprecedented fidelity.

Managing Complexity in Railway Systems through Digital Twins
Railways combine legacy and modern systems, creating a highly complex operating environment. Digital twins provide a structured way to organise and access information across assets, systems, and operational procedures, enabling more consistent decision support, collaboration, and knowledge sharing. This reduces complexity and supports learning, operations, and asset management

Digital Twins for Operational Rehearsal, Training and Performance Support
Digital twins enable operators, dispatchers, planners, and maintenance crews to rehearse operational tasks in a risk-free environment using tools that mirror live operations. Applications include maintenance procedures, traffic control, incident management, driving, and coupling operations. By practising operational workflows, digital twins improve coordination between humans and machines, reduce errors, and strengthen the link between training, testing, and operations.

Digital Twins for Train Driver Simulation
Train simulators have supported driver training for many years, allowing drivers to practise routine operations, degraded modes and emergency scenarios, and familiarise themselves with new infrastructure before it enters service. Connected digital twins can extend these capabilities by reflecting real network conditions, supporting more realistic training and better operational readiness.

Competence Assessment
Evaluation tools analyse user behaviour in simulators, such as reaction times, decision-making, and adherence to rules, helping standardise competence levels across regions and roles. Digital twins will make these tools easier available and closer to real time operations, making them more valuable and accurate.

Together, these developments show how digital environments are becoming essential for preparing staff, enhancing performance in operations, strengthening safety and accelerating the adoption of modern railway technologies.

1. WSP Norway (2026): Digital twin use cases in Norwegian transport sector
2. WSP (2025): Emergency training in digital environments, Cross River Rail, Australia.
3. Mhalla and Dutielleul (2026): Digital Twins and Railway Networks Maintenance: A Partnership for Efficiency and Safety
4. Railways Magazine (2025): Virtual Railways: How Simulation Helps Train the Next Generation of Rail Workers
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6. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications
7. Smart Spatial Blog (2025): 18 Use Cases of Operational Digital Twins in Railways
8. ERRAC (2020) Rail Strategic Research and Innovation Agenda

Digital Training and Operations Score

Overall score

7,7 / 10

Expected value creation from implementation in railway

Digital training and operations score strongly overall, driven by high reliability, cost efficiency, and safety benefits. Digital environments enable safer rehearsal scenarios, standardised competence development, and improved operational preparedness across the railway system. Productivity and cost efficiency gains are solid but more gradual, reflecting continued reliance on human expertise and organisational adoption. Overall, the scoring indicates a high-value, scalable capability that strengthens resilience and safety.

Key Uncertainties

- **Data quality and continuity:** Maintaining accurate, up-to-date data across the asset life cycle remains a challenge for realistic training and reliable operational support.
- **Integration and governance:** Fragmented stakeholders and heterogeneous assets complicate standardisation and integration. Clear responsibilities for model ownership, access, updates and liability are essential for scaling.
- **Model validity and trust:** Confidence in digital training depends on how accurately simulations reflect real operating conditions. Validation is essential to demonstrate that models are fit for their intended use.

Scores above 5 indicate an *improvement* from current railway system*

7/10

Productivity

The application helps identify which processes are suitable for automation and supports in operational readiness but may not lead to direct automation. The primary value is cost reduction and efficiency gains; revenue impacts are typically slower and more indirect.

7,9/10

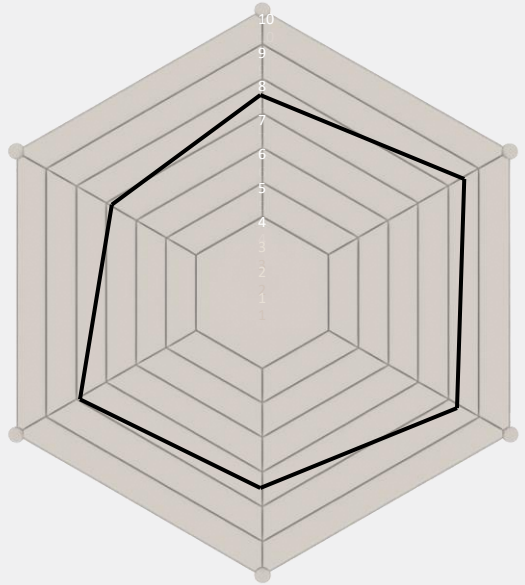
Safety & Security

Improves safety through enhanced training and performance, reducing the risk of failures and incidents, while highlighting the need for robust cybersecurity mitigation as digital dependence increases.

9/10

Cost Efficiency

Large gains as physical training is very costly, especially some tasks. Easy to repeat tasks or training.



8,1/10

Scalability

The technology works well at large scale, with economies of scale. At the same time there are scaling costs to differences in environments, assets and culture.

8,3/10

Reliability

Improved operational performance and fewer errors reduce downtime. However, trust in digital outputs is still evolving.

6/10

Sustainability

Reduces emissions from less physical training, and better use of assets. But in the end the actual operations are the most impactful, which still are performed.

1. WSP Norway (2026): Digital twin use cases in Norwegian transport sector
2. WSP (2025): Emergency training in digital environments, Cross River Rail, Australia.
3. Mhalla and Dutielleul (2026): Digital Twins and Railway Networks Maintenance: A Partnership for Efficiency and Safety
4. Railways Illustrated (2025): Virtual Railways: How Simulation Helps Train the Next Generation of Rail Workers
5. Ricci M. et al. (2025): Exploiting Immersive Virtual Reality for Maintenance Training of Freight Trains
6. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques for Rail Applications

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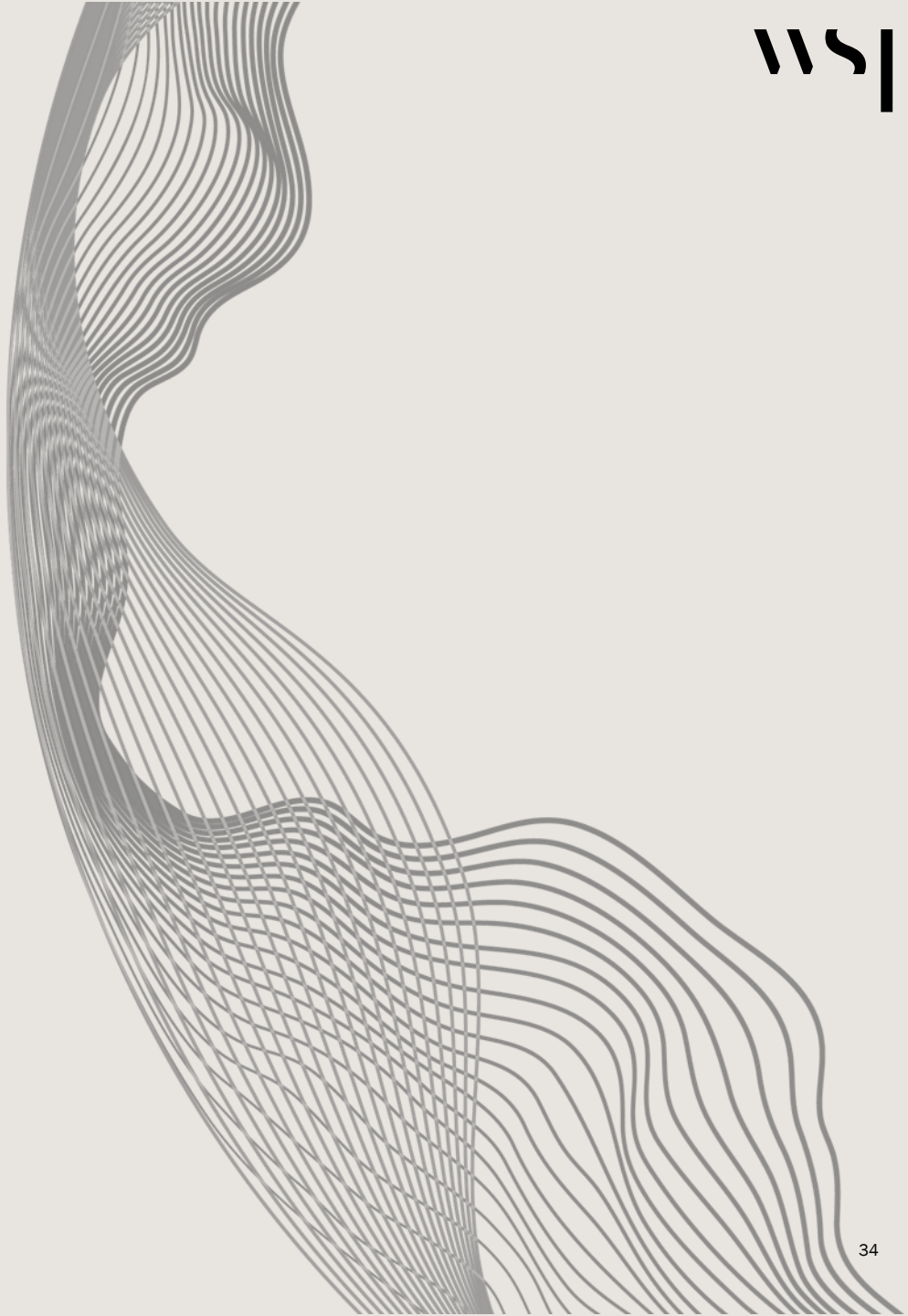
02.6

Summary

Digital twin applications for railway



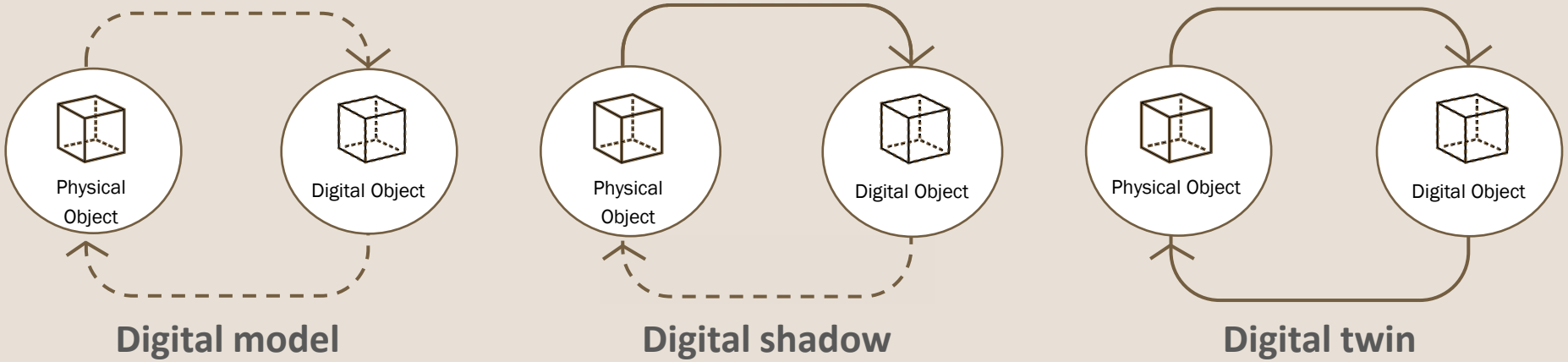
Summary | Digital Twin Fundamentals

Digital twins are defined by the ability to simulate, monitor, analyse, give feedback and support informed decision-making to the object or system that it replicates.

A digital model is a digital representation of a physical object, system or process, updated manually and used primarily for visualisation, analysis and simulation. A digital shadow goes further by automatically receiving data from its physical counterpart, enabling the digital representation to reflect current conditions and support monitoring and analysis. A digital twin combines this continuous connection with the ability to simulate behaviour and scenarios, predict future performance, and provide feedback and decision support to the physical world.

In more advanced applications, it can recommend or initiate actions, although human oversight may remain essential. The key distinction is therefore the increasing flow of data, insight and feedback between the physical and digital environments.

Higher levels of maturity enable increasingly advanced, intelligent, and automated feedback loops



1. WSP Global (2026): *life cycle digital twins*
2. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
3. Europe's Rail (2026). *FP1-MOTIONAL*
4. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle. Bentley Systems eBook.
5. Spiryagin M. et al. (2025): Handbook on Digital Twin and Artificial Intelligence Techniques

Summary | Use Cases and Maturity

Maturity varies across the five application areas and their individual use cases. The table summarises key railway digital twin use cases by assessed maturity, from low to high, considering both technological maturity and readiness for adoption and integration in railway operations.

Life-cycle digital twin use cases are the most mature, building on established BIM, asset information and data-management practices to support condition monitoring, design optimisation and life cycle decision-making. Railway digital testing and predictive maintenance show medium to high maturity, supported by proven simulation and monitoring technologies, although wider deployment depends on data quality, model validation and integration across stakeholders. AI and process automation and digital training and operations are less mature and carry higher implementation risk due to challenges related to trust, cybersecurity, interoperability and organisational adoption. However, these applications also offer significant long-term potential to improve productivity and transform railway operations.

Digital twin railway use case examples, maturity assessment (low-mid-high).

Railway Applications	High Maturity	Medium Maturity	Low Maturity
Life Cycle digital twins	- BIM-based planning, design and delivery - Design and constructability optimisation - Digital network-scale planning - Condition monitoring of railway assets	- Life cycle asset management and decision support - Structural and civil infrastructure assessment - Life cycle and investment planning	- Integrated life cycle twins spanning planning, construction, operation and maintenance - Network-wide, continuously updated digital twins
Railway Digital Testing	- Structural & fatigue testing (FE-based models) - Software- and hardware-in-the-loop (SIL/HIL) validation - Multi-body dynamics simulation (vehicle–track interaction)	- Software-in-the-loop and hardware-in-the-loop validation - Simulation evidence supporting authorisation - Digital testing during railway operation	- Scenario-based operational testing - Integrated life cycle digital testing environment
Railway Predictive Maintenance	- Rolling stock condition prediction (component-level monitoring via TCMS etc.) - Switches and signalling equipment monitoring (trend-based fault detection) - Track/infrastructure health monitoring (geometry, vibration, sensors)	- Structural and civil infrastructure assessment (bridges, tunnels, drainage) - Environmental-risk monitoring and prediction - Asset-health and degradation prediction - Acoustic rail monitoring for loose track detection	- Integrated network-wide prediction models (combined data from trains, sensors, infrastructure) - Digital-twin-enabled maintenance action and optimisation
AI & Process Automation in Rail	- Automated documentation and compliance processes - AI-assisted administrative workflows - Robotised (drone, crawlers or other platforms) infrastructure inspection	- Self-driving / ATO-supported train operations - Digital automatic coupler (DAC) - Robotised infrastructure inspection and field operations - Semi-autonomous terminal and yard operations - Prefabrication and automated production - Automated weather alerting and response recommendations, and automated rockfall and avalanche risk monitoring	- Advanced human-task simulation (dispatchers, planners, maintenance) - Fully autonomous terminal and yard operations - Autonomous operational decision-making without continuous human oversight
Digital Training and Operations	- Digital environments for learning, coordination and performance support - Competence assessment using simulator data and AI - High-fidelity driver simulators connected with digital twin models - Traffic-control and dispatcher simulators	- Rehearsal of maintenance, traffic control, incident response, lifting and coupling operations - VR/AR-based maintenance and operational training - Gamified training using digital models - Managing system complexity through digital twin interfaces - Operational simulation and performance analysis - Operational rehearsal using digital twins	- AI-assisted competence assessment - Digital twins closely linked to real-time operations for training and performance support - Performing operational activities directly within connected digital environments - Continuous feedback on interactions between humans and intelligent railway systems - Integrated training, testing and operational environments

1. Europe's Rail Joint Undertaking (ERJU) – programme, deliverables and digital rail innovation
2. Shift2Rail / Europe's Rail (2019): Digital Twin demonstration
3. Shift2Rail example: Digital twin simulation use cases (stations, operations)
4. McKinsey: Digital twin concept and scaling
5. IBM (2026): Digital twin maturity model
6. Digital Twin Consortium: The Business Maturity Model Is Key to Digital Twin Adoption
7. UIC presentation (2019): The 3DEXPERIENCE platform to foster Innovation in Mobility

Summary | Value assessment

Digital twins create strong economic value when they improve whole-life asset decisions and reduce avoidable failures. By linking design, condition, and performance data, they enable better planning, fewer disruptions, and more efficient maintenance spending across the railway life cycle.

The assessment indicates value potential across all five application areas, with particularly strong performance in cost efficiency, most notably for railway digital testing and digital training, where digital solutions replace traditionally expensive physical testing and training activities.

High value is also derived from reliability, with rail predictive maintenance and life-cycle digital twins achieving the strongest results. Scalability scores indicate that digital twin technologies are inherently scalable, especially for asset-based and stationary infrastructure. Productivity gains are most pronounced for AI process automation, reflecting its potential to streamline administrative and operational workflows.

Risk mitigation scores are high, although increased cybersecurity exposure moderates overall results in safety. Sustainability performance improves compared to today's situation, but actual operations have biggest impact and are set to either speed up or continue in a network with larger capacity derived from digital twin optimisations.

Digital twin value assessment. Benchmark across five key railway digital twin applications based on their potential to improve performance. WSP.



Scores above 5 indicate an *improvement* from current railway system*

Value assessment is provided given Digital twin application implementation.

1. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle
2. WSP Global (2026): *life cycle digital twins*
3. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
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Summary | Economic railway sector impact of digital twins

Digital twin applications generate economic value by reducing life cycle costs, improving asset availability, and enabling more efficient railway operations. Value is primarily driven by reduced unplanned maintenance, improved capacity utilisation, and better data-driven decision-making.

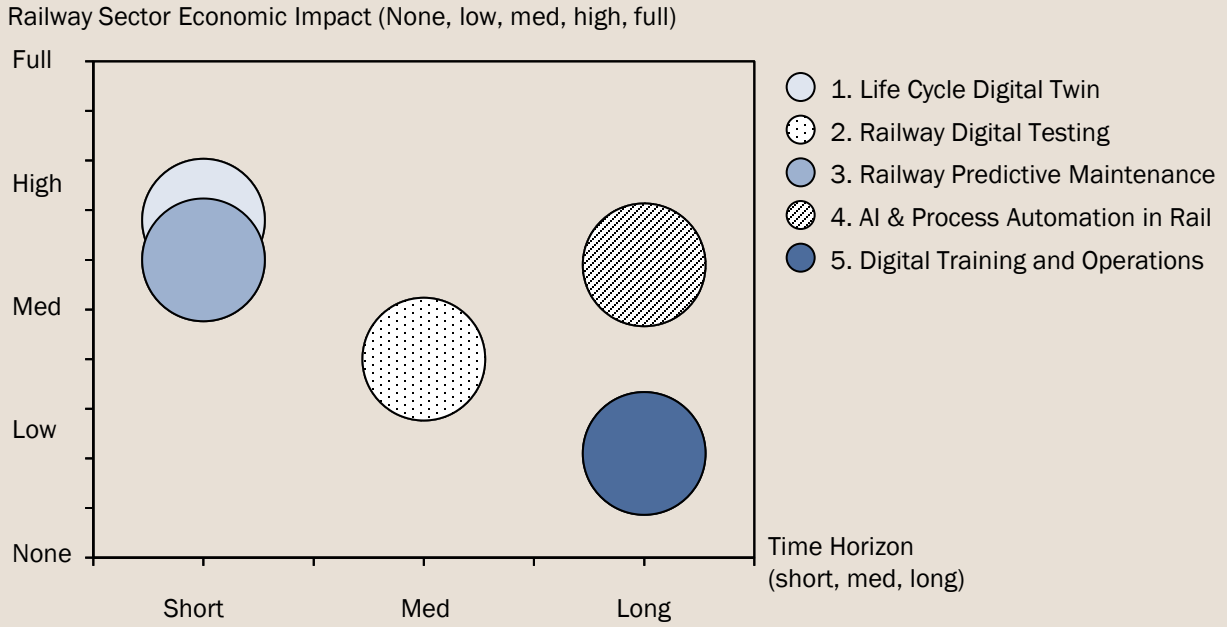
The strongest near-term benefits are seen in predictive maintenance and life cycle applications, where data-driven insights reduce failures and optimise interventions. At system level, integrated digital twins enable network-wide optimisation, improving flow and reducing disruption, with significant multi-year economic benefits.

Long term global value potential

"Digital and AI-driven use cases in rail could unlock $13–22bn annual value globally"
UIC & McKinsey

Looking ahead, the broader adoption of digital twins, AI, and advanced analytics is expected to unlock significant economic potential across the rail sector, driven by productivity gains, improved service quality, and more efficient capital allocation. Thus in the longer horizon AI & process automation in rail is expected to lead the way in economic value creation, as these technologies mature.

Digital Twins, Economic Impact assessment, Railway Sector. WSP.



Sources: WSP expert panel assessment & ORR: Rail Industry Finance (UK)
Note: As a simplification UK railway industry finances are considered representative of the sector.

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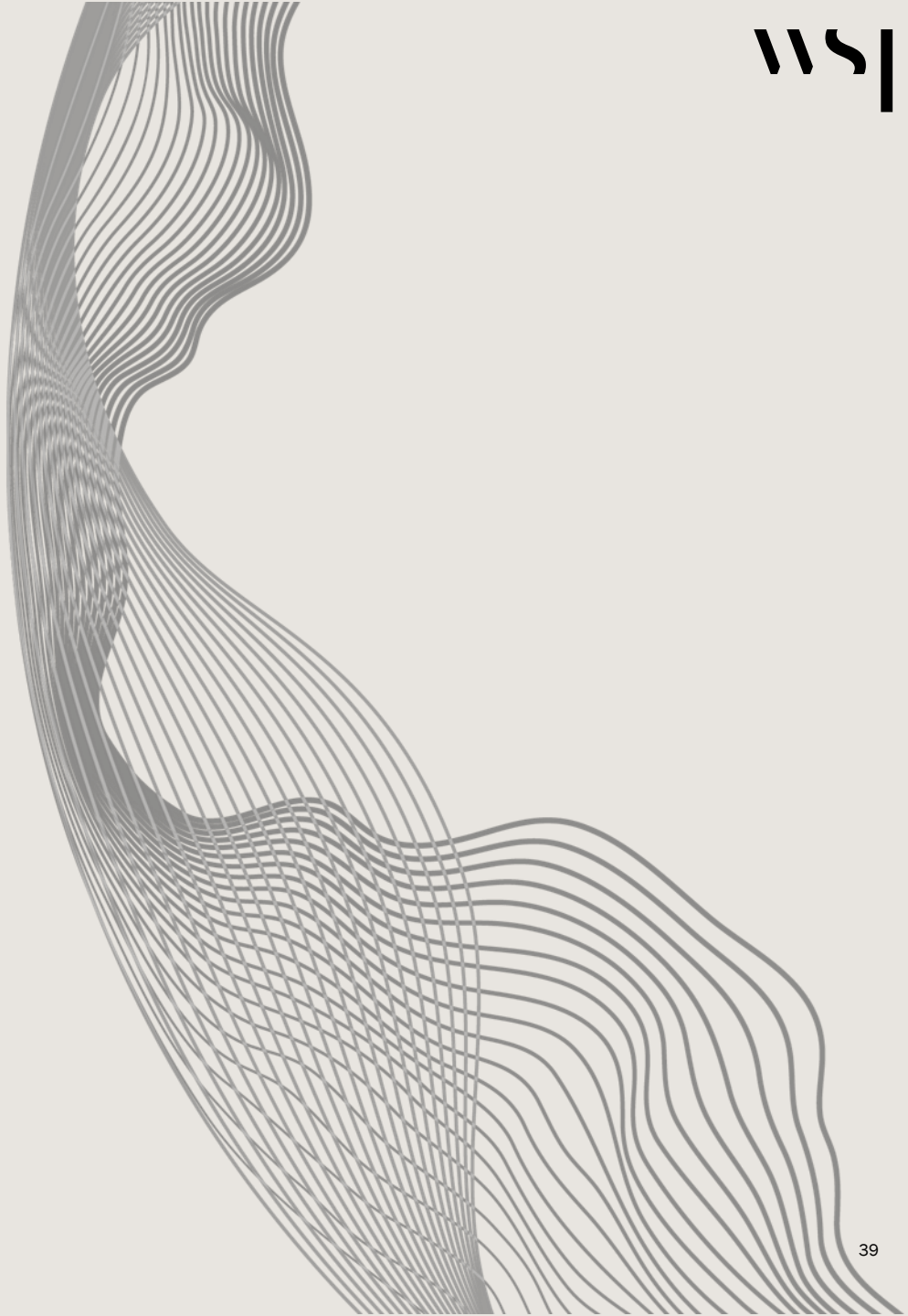
2. ORR: Rail Industry Finance (UK)
3. Douglas Thomas (2024): Economics of digital twins. NIST AMS 100-61
4. BCG (2025): The Route to a Fully Digitized Rail System
5. WSP Global (2026): *life cycle digital twins*
6. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
7. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle. Bentley Systems eBook.
8. UIC & McKinsey: The journey toward AI-enabled railway companies

Note: To provide a sense of scale, full yearly cost of British railway was ~£11.1bn in 2025. Compared to the UIC McK yearly global estimate of ~£10-17bn.

03

Global Best Practices in Railway Digital Twin Adoption



Steadfast on Cybersecurity

Cybersecurity is a critical consideration in the adoption of digital twins within the railway sector. As digital twins increasingly integrate physical assets, operational systems, and decision-support tools into connected data environments, they also expand the potential cyber-attack surface. Global best practice shows that cybersecurity must be treated as a core governance and life cycle issue, rather than a standalone technical concern.

Digital twins offer substantial benefits for railway operations, but increased connectivity also introduces cybersecurity risks. Increased connectivity exposes safety-critical railway functions if boundaries are unclear or poorly enforced. Real-time data exchange, remote access, and collaboration with external partners increase the number of potential entry points. Weak access control or insufficient segregation of environments can undermine trust in digital twin outputs and, in worst-case scenarios, affect operational safety.

Global best practice therefore emphasises a secure-by-design approach. Cybersecurity requirements are embedded early in architecture design, data governance, and access management, with clear separation between safety-critical systems and analytical or decision-support layers. Leading organisations apply defence-in-depth principles and manage third-party access systematically.

This approach involves trade-offs. Strong cybersecurity controls can increase cost, complexity, and implementation time, potentially slowing innovation and early experimentation. Overly restrictive policies may also limit data sharing across stakeholders, reducing the overall value of digital twins in a highly collaborative railway ecosystem. Balancing openness and security is therefore essential. Best-performing organisations apply risk-based and proportionate approaches to cybersecurity.



1. European Union Agency for Cybersecurity (ENISA) (2026): Railway Cybersecurity: Good Practices in Cyber Risk Management
2. WSP Global (2024, 2025) Artificial Intelligence Policy
3. European Union Agency for Railways (ERA): Cybersecurity in Railways
4. ERA & ENISA Memorandum of Understanding (MoU)

Building Trust

Trust is a critical prerequisite for the successful adoption of digital twins in the railway sector. Digital twins increasingly inform decisions related to safety, operations, maintenance, and long-term investment planning. For operators, asset owners, suppliers, and regulators to rely on these insights, trust must extend beyond individual technologies to encompass the entire digital ecosystem – data, models, tools, processes, and the organisations that develop and use them.

Global best practice shows that trust is built gradually through validation, traceability, and clear governance. This applies not only to AI-enabled analytics, but also to BIM models, simulation environments, data management, and digital-twin workflows.

Trust also has a strong organisational dimension. Digital twins often span multiple stakeholders. Confidence in shared models depends on agreed roles, responsibilities, and liabilities, as well as consistent standards and interfaces. Without such trust, even technically sound digital twins risk limited adoption or fragmented use. At the same time, over-reliance on automation introduces risks. Complex models can obscure uncertainty or create false confidence if limitations are not clearly communicated. Poor data quality, insufficient validation, or rapid deployment without operational learning can undermine acceptance among engineers, operators, and regulators.

Leading railway organisations therefore adopt a balanced, incremental approach. Digital twins are introduced as decision-support tools before progressing toward higher levels of automation, allowing trust to develop through proven performance in real operations. Human-in-the-loop processes remain essential to preserve accountability, professional judgment, and operational responsibility—enabling safer, more efficient, and more resilient railway systems.



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2. NIST (2023). AI Risk Management Framework 1.0
3. ENISA & ERA. Railway Cybersecurity and Risk Management
4. Flammini et al. (2025). Handbook on Digital Twin & AI Techniques for Rail Applications
5. SAFEXPLAIN (EU). Explainable AI for Safety-Critical Rail Systems
6. Digitale Schiene Deutschland (2025). Digital Twins for Automated Rail Operations
7. WSP Global (2025). Transportation AI Field Guide

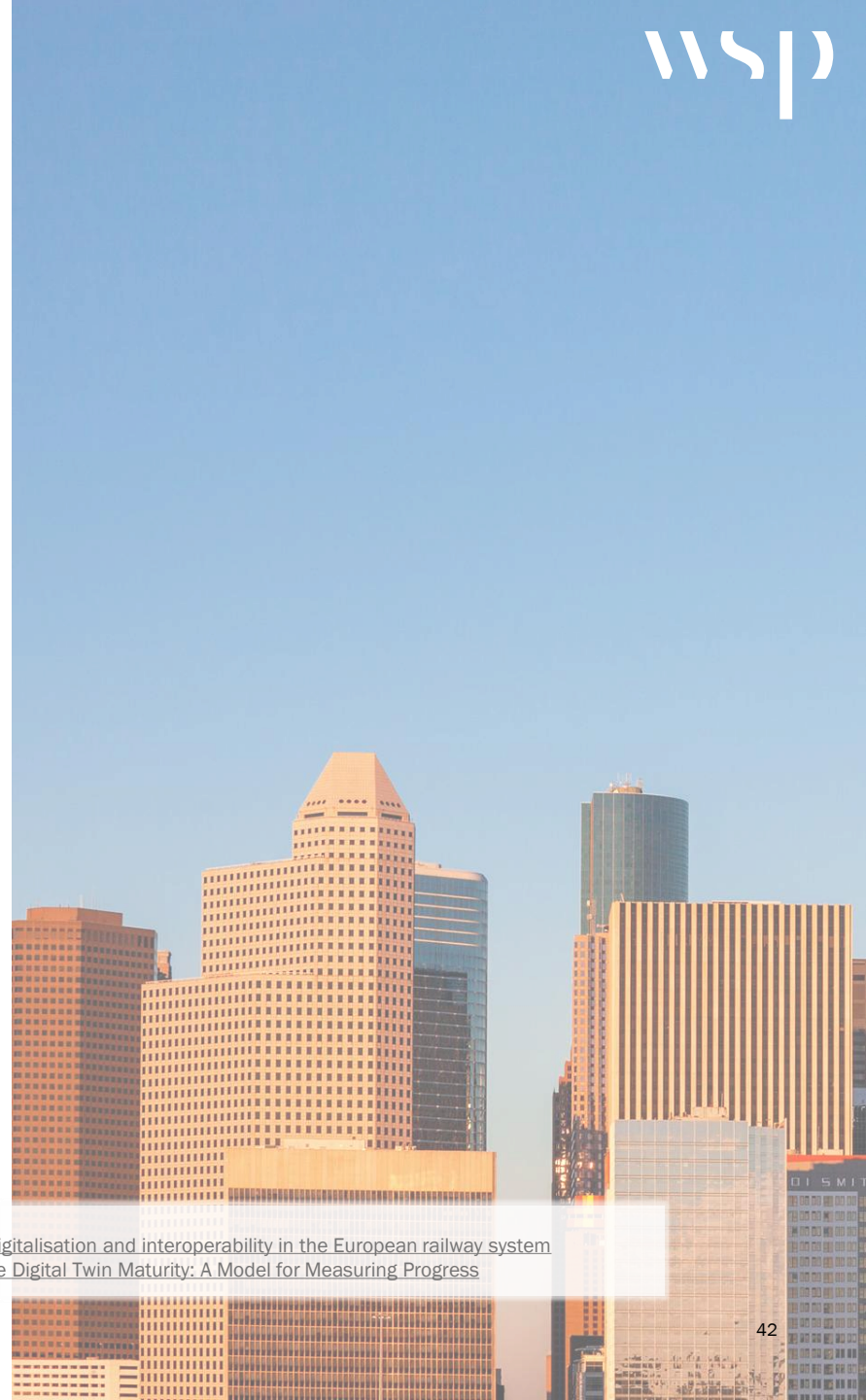
Standardisation as Key for Scaling

Standardisation is essential for successful digital twin adoption in the railway sector. As digital twins span infrastructure, rolling stock, operations, and multiple stakeholders, common standards for data models, interfaces, semantics, and governance are critical to ensure interoperability and long-term value. Global best practice shows that standardisation allows digital twins to scale beyond isolated pilots, enabling cross-asset analytics, supplier collaboration, and life cycle continuity across planning, construction, and operations.

Standardisation delivers clear benefits by reducing integration costs, limiting vendor lock-in, and enabling reuse of data, models, and tools across projects. In a highly interconnected railway ecosystem, shared data structures improve collaboration, transparency, and traceability, critical as digital twins support safety-critical decisions, regulatory compliance, and long-term investment planning. Over time, standardisation helps ensure digital twins remain usable across long asset life cycles and facilitates faster scaling across assets and organisations.

However, it also involves trade-offs: developing common standards can be slow in a landscape shaped by legacy systems and national regulations, while over-standardisation may increase cost, complexity, and slow innovation, particularly in early adoption phases where technology evolves faster than global standards.

Best practice therefore favours a balanced approach. Leading railway organisations combine open, widely accepted standards for core data, interfaces, and governance with flexibility at the application level. This enables innovation while preserving interoperability and long-term sustainability. Rather than a one-off technical exercise, standardisation is managed as an evolving capability aligned with digital maturity, regulatory needs, and the growing strategic importance of digital twins.



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2. IEEE Access (2023): Digital Twin for Railway: A Comprehensive Survey
3. Bentley Systems Digital Twins Drive Better Outcomes across the Rail Asset life cycle
4. BuildingSMART International – IFC / openBIM standards for infrastructure and asset life cycle data
5. Functional Mock-up Interface
6. European Union Agency for Railways (ERA): Digitalisation and interoperability in the European railway system
7. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress

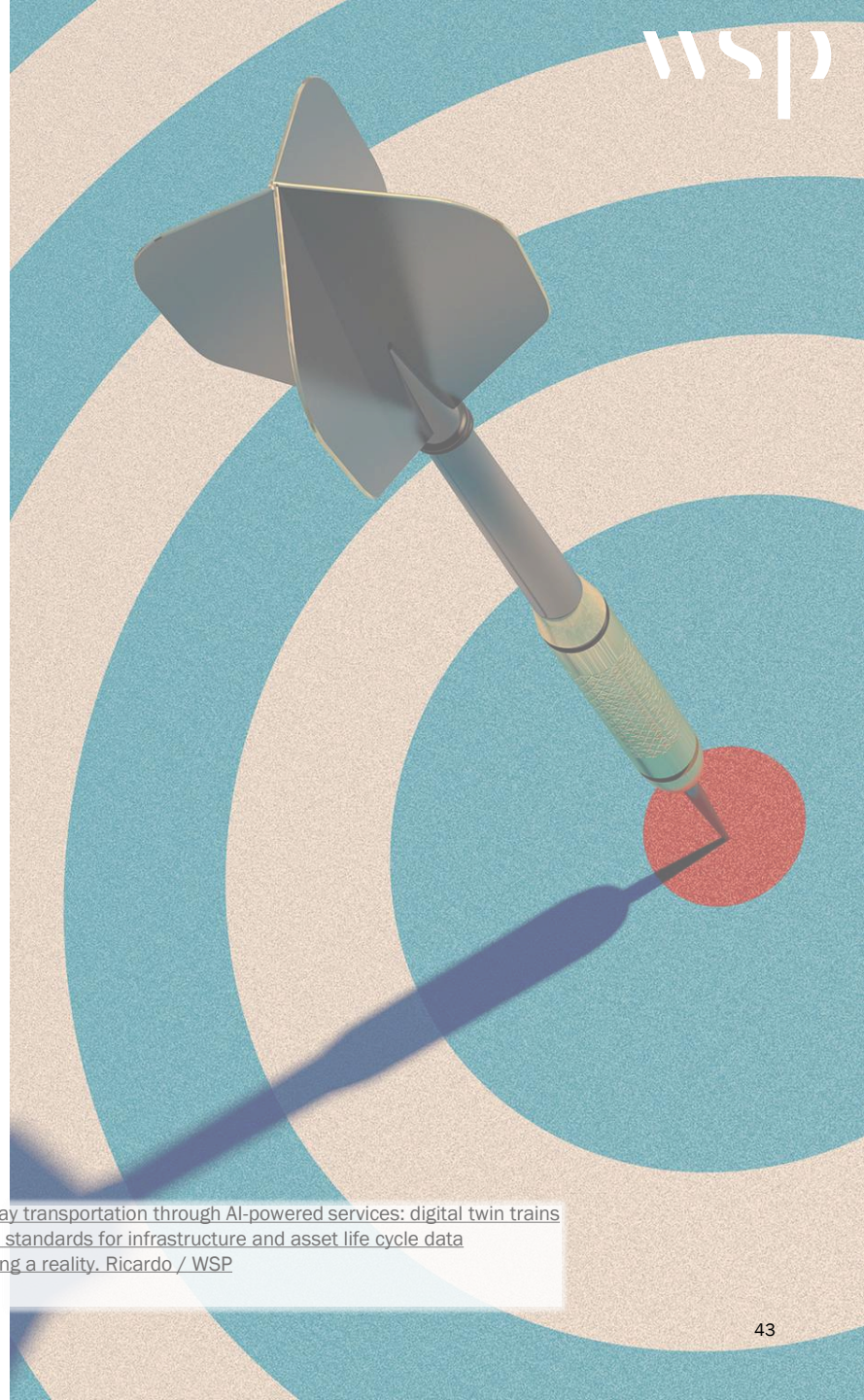
Focus on Implementation

Successful implementation of digital twins in the railway sector requires more than the deployment of advanced technology. Global best practice shows that value is realised when digital twins are introduced as part of a coordinated transformation of data, processes, governance, and organisational capabilities. Railway organisations that succeed typically adopt a phased and use-case–driven approach, starting with clearly defined operational or planning needs and gradually expanding scope as data maturity and confidence increase.

A key advantage of a structured implementation approach is reduced risk. Another important dimension is speed. Speed is important to gain enough return on investment and thereby providing productivity and cost efficiency in the railway sector. Finding a good implementation practice will have huge impacts over time. McKinsey estimates that digital twins can improve public sector capital and operational efficiency by 20 to 30 percent.

However, implementation also presents challenges. Many railway organisations struggle with fragmented legacy systems, inconsistent standards, and unclear data ownership. Addressing these issues requires upfront investment in digital foundations, integration capabilities, and skills, making implementation resource-intensive and potentially competing with short-term operational priorities. If ambitions exceed organisational readiness, there is a risk of over-complex solutions with limited practical value.

Global experience highlights the need to balance ambition with pragmatism. Leading organisations align implementation with long-term strategy while retaining flexibility in execution. Clear governance, defined responsibilities, and collaboration across public and private stakeholders are critical enablers. Rather than a one-off project (usually associated with high risk and high cost), digital twin adoption is managed as a continuous capability that evolves with technology, regulation, and operational needs.



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3. European Union Agency for Railways (2025): Annual Overview for Interoperability
4. McKinsey & Company (2025): Digital twins: Boosting ROI of government infrastructure investments
5. Springer Nature (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
6. BuildingSMART International – IFC / openBIM standards for infrastructure and asset life cycle data
7. Vermeij, I. (2025): Making virtual railway testing a reality. Ricardo / WSP

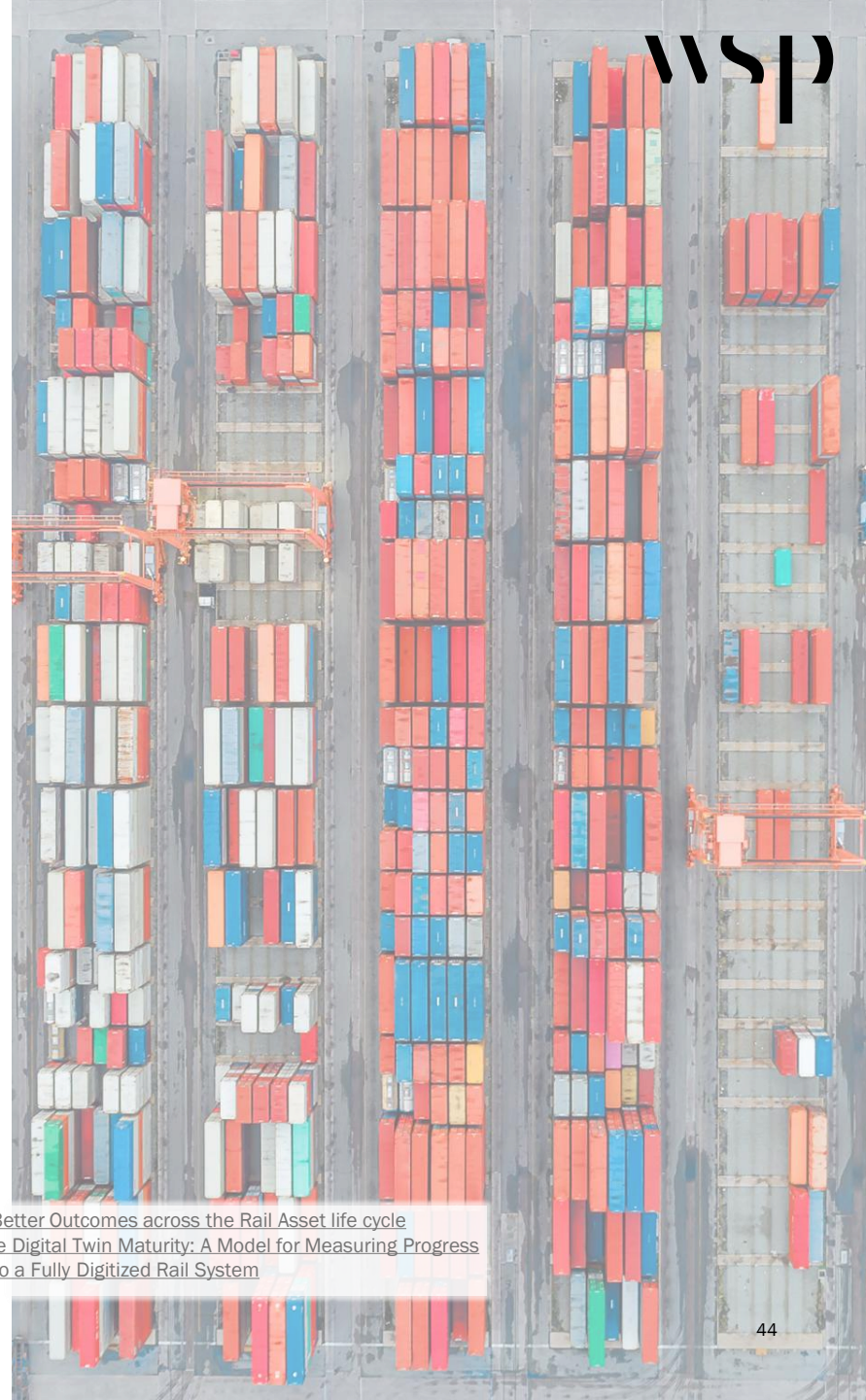
Portfolio Management with Clear Objectives

Global best practice supports a shift from traditional, silo-based railway budgeting toward portfolio management with clear, outcome-driven goals when implementing digital twins. Instead of fixed budgets by asset or organisation, leading railways manage digital twin initiatives as a portfolio aligned with strategic objectives such as safety, reliability, capacity, sustainability, and productivity. This enables comparison across domains, prioritisation of high-value initiatives, and flexible reallocation of resources as evidence of impact emerges.

A key advantage of portfolio-based management is stronger strategic alignment and transparency. Because digital twin initiatives cut across infrastructure, rolling stock, and operations, a portfolio approach allows benefits, risks, and dependencies to be assessed holistically. It supports informed trade-offs between short-term operational needs and long-term transformation, while enabling experimentation and adjustment as initiatives mature.

However, portfolio management also introduces challenges. It requires stronger governance, clearer ownership, and consistent performance measurement across the sector with diverse use cases. Benefits are often indirect or long-term, making comparison difficult and continuity can be challenged with frequent and shifting political and management leadership. Reprioritisation can create uncertainty or slow delivery.

Global experience shows that successful organisations balance flexibility with discipline. Clear, measurable objectives aligned with long-term goals, and strong governance ensure that portfolio management supports operational stability while steering digital twin investments toward measurable outcomes in an increasingly data-driven railway sector.



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2. Springer Nature (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
3. Springer Nature (2023): The Potential Value of Digital Twin in Rail and Road Infrastructure Asset Management
4. Bentley Systems (2023): Digital Twins Drive Better Outcomes across the Rail Asset life cycle
5. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress
6. Boston Consulting Group (2025): The Route to a Fully Digitized Rail System

Involve Sector Expertise

Global best practice shows that effective development and implementation of digital twin technology in the railway sector increasingly relies on active engagement with sector expertise. Digital twins combine advanced software, data platforms, analytics, artificial intelligence, and systems integration – capabilities that often evolve faster in the private technology market. By engaging industry partners, rail authorities can access specialised skills, proven tools, and experience with digitalising industrial operations that accelerate development and reduce technical risk.

One of the key advantages of private-sector involvement is speed and innovation. Experience from multiple sectors and international projects enables faster learning and reuse of mature solutions. This reduces risk of costly solutions and increases the likelihood of achieving objectives on digital initiatives such as digital twins.

The railway sector is in many countries often associated with long traditions, a heavily regulated landscape, high safety standards, and a high degree of public ownership. A stronger degree of portfolio management is one key to a higher degree of private involvement.

However, increased reliance on private expertise also introduces challenges. Strong private involvement may create dependencies on suppliers, increase exposure to vendor lock-in or reduce transparency. There is also a risk that commercial incentives drive technology choices that are misaligned with long-term public objectives, such as life cycle cost efficiency, interoperability, or national ownership of critical data and knowledge. Effective procurement, clear requirements, and strong governance are therefore essential.

Railway organisations should retain strategic ownership of goals, data and architecture while drawing on private-sector expertise. Clear contracts, open standards, and knowledge-transfer mechanisms help ensure that competence is built within the sector over time.



1. Ricardo/WSP (2025): Opportunities and challenges in sharing railway digital twins
2. WSP, Dassault Systèmes and Deutsche Bahn (2023): Enterprise Asset Management and Digitalization of Rail Systems
3. Springer Nature (2024): Digitalization of railway transportation through AI-powered services: digital twin trains
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5. Bentley Systems (2023): Digital Twins Drive Better Outcomes across the Rail Asset life cycle
6. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress
7. Boston Consulting Group (2025): The Route to a Fully Digitized Rail System

Data is fundamental

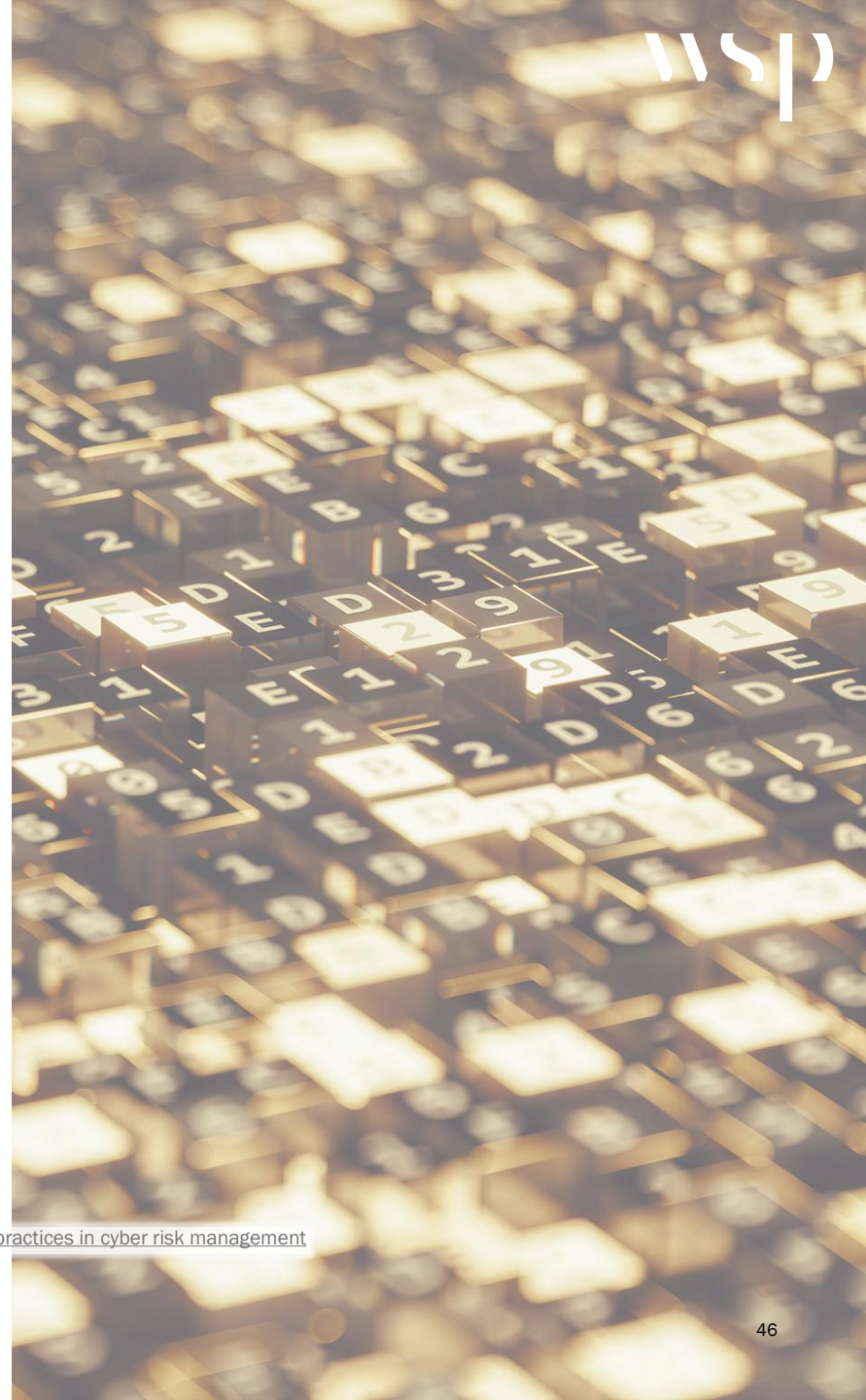
Data underpins digital twin adoption in railways. Combining data across assets, systems, organisations, and life cycle phases provides a more complete understanding of railway performance. Successful initiatives use structured data sharing to support collaboration and insights while protecting sensitive and safety-critical information. The challenge is to enable sharing that delivers value while balancing openness with governance, security, and trust.

Digital twins live or die by data, and three dimensions are particularly important. First, data must be available. Second, data quality must be ensured. Third, there must be a culture and platforms that enable data sharing. All three are fundamental prerequisites for digital twins to deliver value.

Data availability has increased significantly due to the lower cost and wider deployment of sensing technologies such as cameras, lidar, and other sensors. In parallel, synthetic data is increasingly used as a complementary source. Digitalisation and regulatory openness to data sharing is fundamental. At the same time, increased availability raises the importance of cybersecurity.

Data quality has a decisive impact on all digital-twin value propositions. At a basic level, it concerns filtering, validation, and cleaning of data. At a more advanced level, quality is closely tied to the specific problems the data is intended to address. Edge processing is increasingly used as a cost-efficient mechanism to reduce data volumes and tailor data streams to specific analytical needs.

Finally, data must be shared to create value. Effective data sharing depends not only on technical solutions, but also on organisational culture, trust, and maturity. Mechanisms for sharing data must therefore balance value creation with control, ensuring that data can be used where it creates insight while protecting critical interests.



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2. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress.
3. ERRAC (2020): Rail Strategic Research and Innovation Agenda
4. ENISA (2026): Railway cybersecurity – Good practices in cyber risk management

Need for backup systems

Resilience is a core design principle for railway digital twins. As railways integrate them into planning and operations, they must prepare for power outages, cyber incidents, supplier disruptions, regulatory interventions and unexpected system behaviour. Backup systems help maintain operational continuity, trust in digital outputs and safety when primary services are degraded or unavailable.

Resilience must span multiple layers. Energy supply is fundamental: upstream energy supply, data centres, sensor networks, control rooms, and cloud services that host digital twins require redundant power sources, failover capacity, and prioritised access to electricity during grid stress. Similarly, data and computation need redundancy across locations and platforms to avoid single points of failure. For digital twins, backup strategies should also cover applications and fallback operational procedures.

Dependency risks must also be actively managed. Best practice shows the need for contractual safeguards, exit strategies, and contingency arrangements for disruptions affecting the systems.

At the same time, extensive backup systems come with trade-offs. Redundancy increases cost, complexity, and operational overhead, potentially slowing innovation. Global best practice therefore emphasises a risk-based and proportionate approach: backup systems should be aligned with the criticality of the digital twin application, organisational maturity and potential consequences of failure. Well-designed backup strategies support confident adoption of digital twins by helping railways maintain operational continuity, safeguard safety and preserve public trust during system failures.



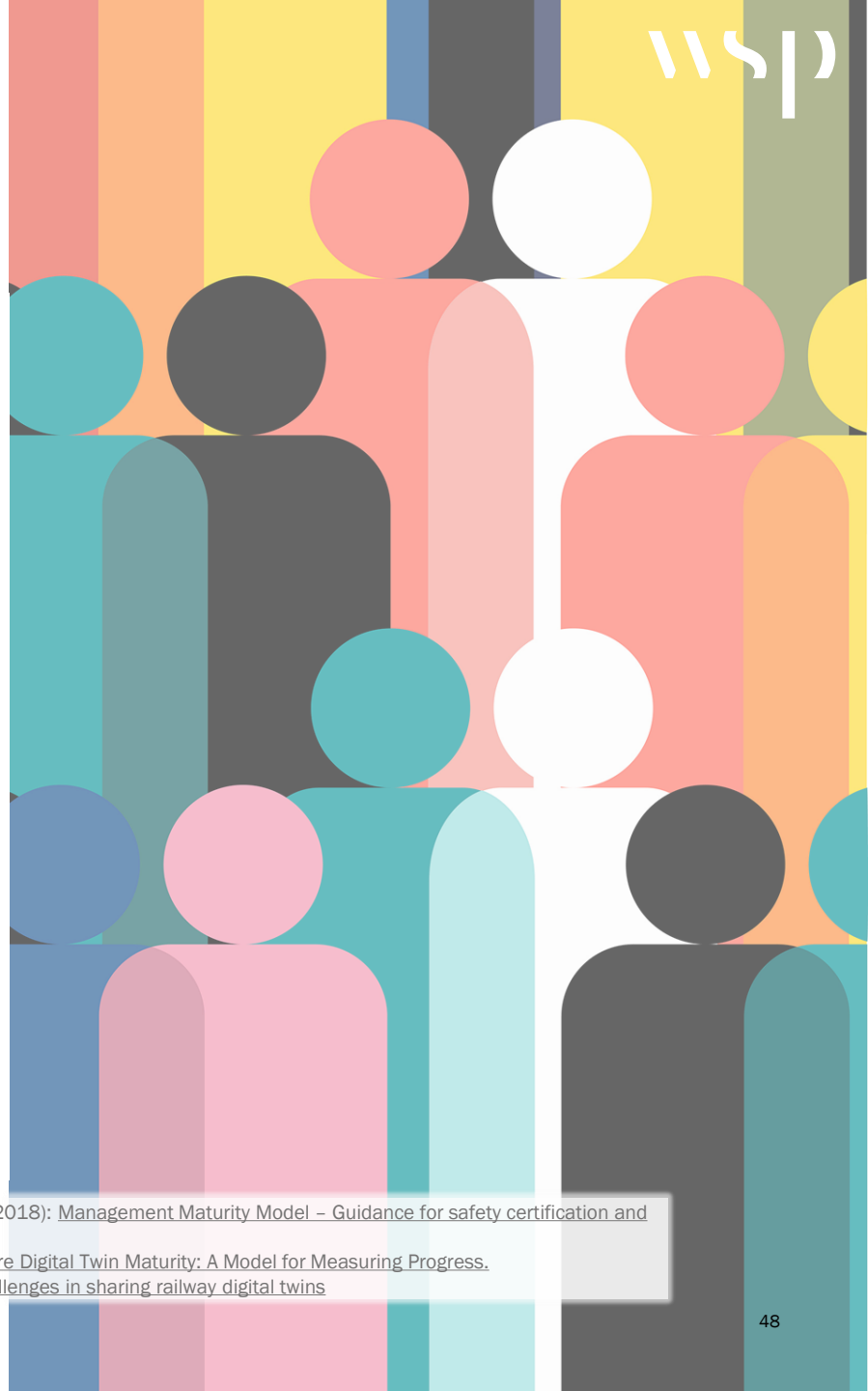
1. European Union Agency for Cybersecurity – ENISA (2026): Railway cybersecurity – Good practices in cyber risk management.
2. European Union Agency for Railways – ERA (2025): Cybersecurity in the railway system.
3. NIST (2023): AI Risk Management Framework (AI RMF 1.0).
4. CBS News (2026): Internal Pentagon memo on Anthropic (reported by CBS News) (2026)
5. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity – A model for measuring progress.
6. UIC – International Union of Railways (2026): Railway Digital Modelling and Rail System Model (RSM).

Culture and organisations leading the way

Culture and organisational maturity are decisive for successful digital twin adoption in railways. Global best practice favours treating digital twins as long-term capabilities for sustained value. Committed leadership and clear ownership support continuous learning, helping digital twins evolve across asset life cycles and organisational boundaries. This maturity brings engineering knowledge together with operational data and digital models to inform everyday decisions.

Organisations with higher maturity are better positioned to use digital twins not only for analysis, but as decision-support tools embedded in planning, operations, and maintenance workflows. At the same time, developing such maturity requires sustained investment in skills, governance, and change management. In traditionally risk-averse and safety-critical railway organisations, resistance to change and reliance on established processes can slow adoption. Digital twins challenge existing roles, responsibilities, and decision hierarchies, which may create uncertainty or scepticism if benefits are not clearly demonstrated.
Over-ambitious initiatives introduced without sufficient organisational readiness risk becoming complex solutions with limited practical impact, increasing cost and undermining confidence in digital approaches.

Best practice therefore emphasises a stepwise approach. Organisations leading the way align digital twin ambitions with their organisational maturity, starting with well-defined problems where value is tangible and risks are manageable. A fundamental building block is fostering a culture that prioritises high data quality, supported by clear routines and well-defined procedures. Organisations should develop culture, competence and trust alongside the technology and applications, rather than being treated as prerequisites that must be fully resolved upfront. This balanced approach enables long-term value creation while safeguarding safety, reliability, and operational stability – core priorities in the railway sector.



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4. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity: A Model for Measuring Progress.
5. Ricardo/WSP (2025): Opportunities and challenges in sharing railway digital twins

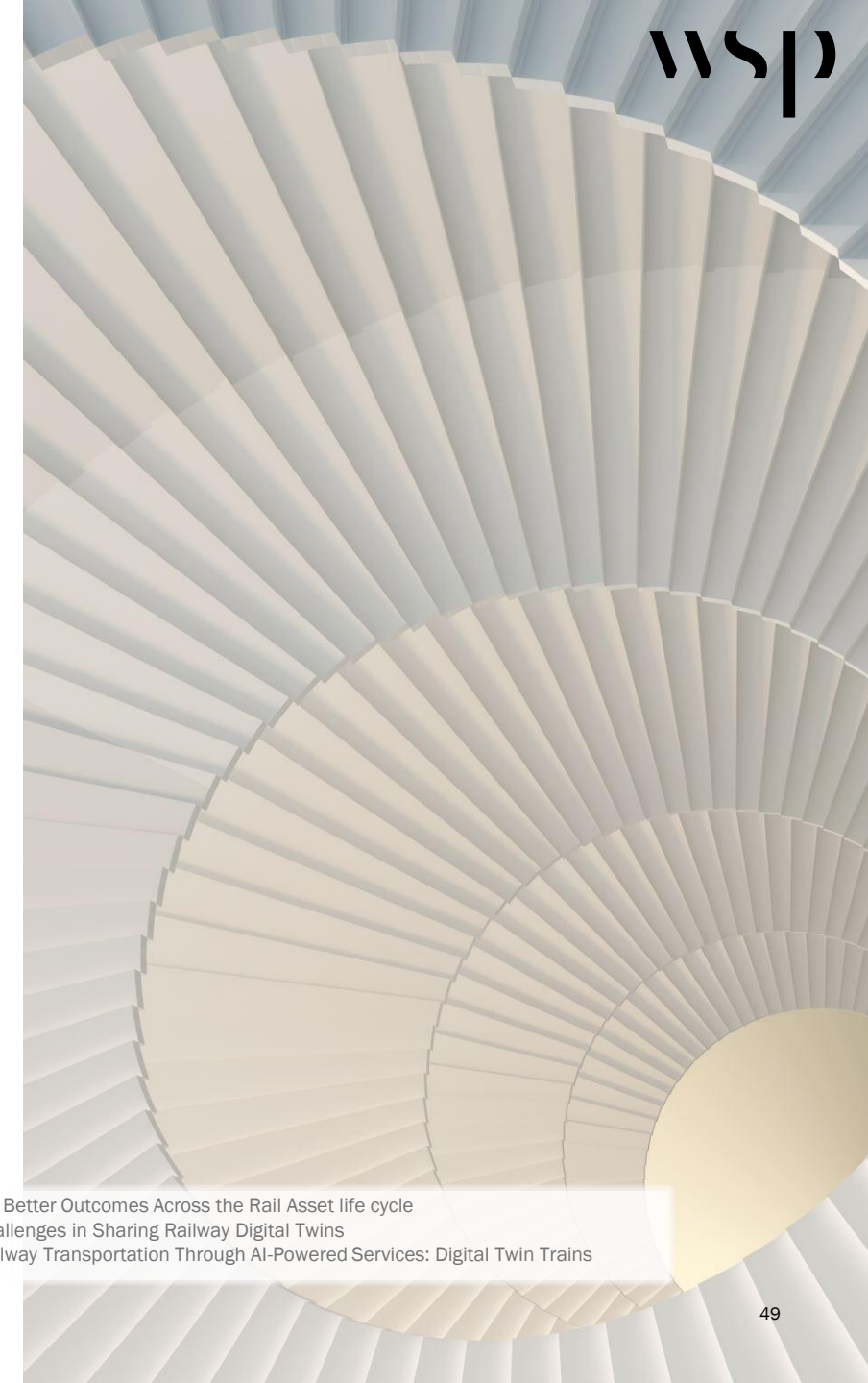
Start stepwise with problem solving

Global best practice favours railway digital twin initiatives that start with clearly defined problems. A stepwise approach targets understood operational challenges, costs and safety risks where digital twins can deliver early value. Typical starting points include costly maintenance, capacity bottlenecks, safety-critical assets and recurring disruptions, keeping investment focused on practical needs.

The primary advantage of this approach is cost efficiency. By limiting initial scope, organisations reduce upfront investment in data infrastructure, modelling complexity, and system integration. Early digital twin implementations can often reuse existing data sources and models, allowing value to be demonstrated without large capital commitments. This lowers financial risk, shortens time to benefit, and improves the credibility of digital twin investments among decision-makers. Early wins also provide evidence for scaling, helping justify subsequent investments based on measured performance improvements, cost reductions, or avoided failures. A stepwise approach also strengthens value creation by ensuring alignment with operational needs.

However, this approach also has limitations. Focusing narrowly on individual problems can lead to fragmented solutions without shared governance and data standards. Local optimisation may delay system-wide benefits, and repeated point solutions can increase integration costs later if interoperability is not planned. Overall, an incremental progress may be perceived as slow.

Best practice therefore balances pragmatism with strategic intent. Successful railway organisations combine stepwise problem solving with a clear long-term vision, allowing early investments to support a scalable digital foundation.



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04

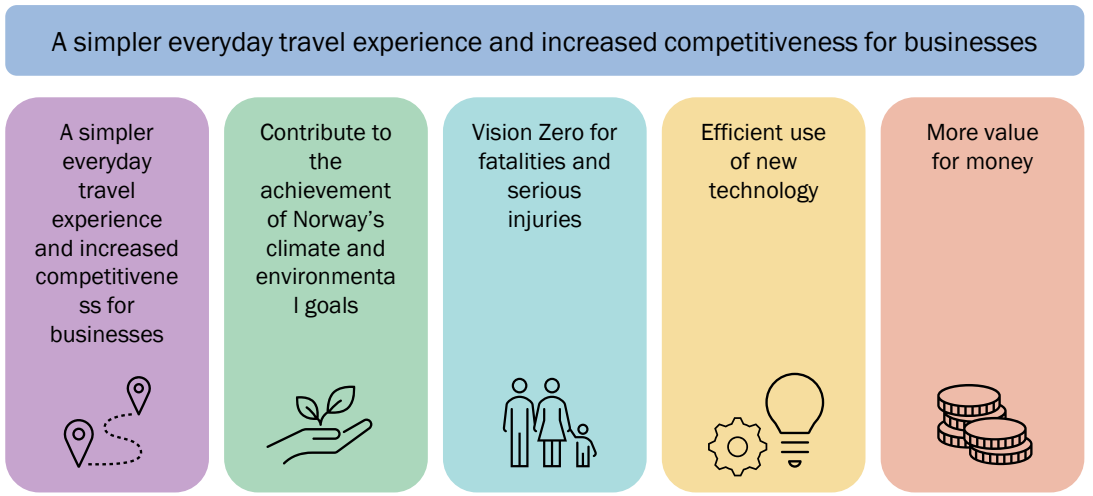
Norwegian railway landscape
- Digital twin initiatives and use cases

Introduction to The Norwegian Railway Sector

The Norwegian railway sector is a complex, publicly governed ecosystem with long-lived infrastructure, high safety requirements, and strong societal importance. It is organised with a separation between policy and coordination, infrastructure ownership and management, train operations, and service delivery to passengers and freight customers.

The Norwegian transport sector is guided by overarching goals defined in the twelve-year National Transport Plan (NTP), which sets priorities for addressing the sector's most critical challenges. These goals are shown in the figure below. Digital twins can support several of these objectives.

In Norway, passenger rail traffic is concentrated in the Oslo capital region, where regional and local rail services are extensively used. Nearly 80 percent of all rail journeys take place within this area. Rail freight mainly serves Norway's five largest cities and carries salmon southwards from Norway to markets in Central Europe.



Goals for the Norwegian transport sector (NTP-goals)



Norwegian railway map

1. SSB Rail traffic
2. Norwegian Ministry of Transport – National Transport Plan 2022–2033

A gradual digital transformation

The Norwegian railway sector is increasingly aligned around using technology and digitalisation to improve efficiency, reliability, cost control, and progress toward climate and safety goals. The sector operates within a regulated environment, balancing national transport goals with European interoperability requirements.

The Norwegian railway sector faces increasing pressure to improve reliability, capacity in bottlenecks and cost efficiency while managing aging assets. Climate change and more extreme weather place greater strain on infrastructure. In 2023 the main railway line south-north, Dovrebanen, was closed for 9 months after a flood that caused severe damage to a bridge. In 2025, rush-hour punctuality in the greater Oslo area was 78%, and trains were heavily crowded. For freight, punctuality is slightly lower. There have been frequent signal errors and issues resulting from old and worn infrastructure at some locations and a lack of rolling stock. Several measures are taken to improve conditions, but lead times are long.

At the same time, the sector is gradually adopting digital technologies, where use of new technology is increasingly addressed. Key priorities in this transition include digitalisation and a more data-driven railway, smarter maintenance to reduce costs and extend the lifespan of infrastructure, and investment in ERTMS. To support these priorities, several governmental agencies have strengthened their capacity through recruitment. However, establishing a shared direction and achieving effective cross-sector collaboration with clear objectives is complex, and progress has therefore been gradual – often driven by committed individuals rather than coordinated structures. Nevertheless, the Norwegian railway sector is steadily moving toward a more digital and automated future. Through this the sector aims to realise tangible benefits while safeguarding safety, reliability, and public trust.



Three key government documents addressing technology adoption the last years

1. Bane NOR (2026): Punktlighetsstatistikk – Rushtid i Oslo og nasjonale nøkkeltall
2. NRK (2023): Jernbanebrua på Dovrebanen kollapset under ekstremvær («Hans»)
3. Jernbanedirektoratet (2024): Randklev-bruddet kostet samfunnet 1,4 milliarder kroner
4. Bane NOR (2024): Re-planlegging av ERTMS – status og ny tidslinje for Norge
5. Ministry of Transport (2021): National Transport Plan 2022–2033 (NTP)
6. NTP 2025-2026: Vedlegg 3: Teknologi og FoUI
7. Jernbanedirektoratet (2026): Syv strategiske retninger for teknologi og innovasjon i jernbanen 2025-2030.

Latest developments on Digital twins

The Norwegian railway sector is building a growing portfolio of digital twins, AI, automation, and digitalisation initiatives across infrastructure, rolling stock, terminals, and network operations. Together, these initiatives demonstrate a shift from static asset-focused models and pilots toward more predictive and data-driven solutions aimed at improving railway operations and customer satisfaction. Scaling successful initiatives and establishing clearer sector-wide prioritisation will be important next steps.

Current initiatives focus on infrastructure monitoring, asset management, simulation, and operational optimisation. Examples include condition monitoring of bridges, tunnels, switches, and rolling stock; remaining-life estimation; digital infrastructure models (DIM); timetable simulations; and passenger-flow modelling. Increasingly, these solutions combine AI, computer vision, machine learning, and advanced simulation technologies.

Notable examples include the IARI and AUTOKONTROLL programmes that use cameras, sensors, and AI to automate railway inspections and support predictive maintenance. Similar approaches are applied to image-based monitoring of infrastructure and environmental risks. The sector is also experimenting with digital twins and optimisation tools such as DIM, timetable digital twins, station dwell-time simulations, Track Assignment Optimiser at Alnabru, Togiro, TIOS-A, and terminal management systems that improve capacity utilisation and operational efficiency.

A growing number of initiatives focus on automation and intelligent sensing. Examples include autonomous terminal equipment, onboard diagnostics, infrastructure monitoring from infrastructure inspection train, and TrainVision, an NGI concept that uses imagery collected from regular service trains to monitor railway corridors and surrounding terrain. Similar approaches are being explored for tunnels, bridges, track assets, and geotechnical conditions. Innovation efforts are supported through collaboration between railway organisations, technology suppliers, and research institutions including SINTEF, NORCE, NGI, IFE, NTNU, and Norwegian Computing Centre*. Several of Europe's rail flagship projects such as IAM4RAIL, R2DATO, MOTIONAL, FutuRe and TRANS4M-R help bring international innovation to Norwegian railway conditions.

Overall, the Norwegian railway innovation portfolio reflects a pragmatic approach focused on solving high-value operational challenges, building data maturity, and testing new technologies through targeted pilots. The next challenge will be to systematically prioritise and scale the most promising use cases through stronger coordination, industry partnerships, and government support, enabling a more predictive, integrated, and intelligent railway system.

1. Europe's Rail Joint Undertaking (2025): Europe's Rail Innovation Programme, Flagship Projects MOTIONAL, IAM4RAIL, R2DATO, TRANS4M-R and FutuRe
2. Bane NOR (2026): Digital infrastrukturmodell (DIM)
3. Norsk Regnesentral & Bane NOR (2025): AutoKontroll – Automated railway inspection using AI and train-mounted cameras
4. Diverse poster på LinkedIn (2023-2026): Autokontroll, TrainVision, TrainGate, Togiro, IARI, Europe's Rail

Note: *Abbreviations: SINTEF (Foundation for Industrial and Technical Research), NORCE (Norwegian Research Centre), NGI (Norwegian Geotechnical Institute), IFE (Institute for Energy Technology (Institutt for energiteknikk)), NTNU (Norwegian University of Science and Technology)

From pilot cases to implementation

Many of the use cases demonstrate how digital technologies can transform the Norwegian railway sector by delivering tangible value and leveraging international technology developments adapted to a Norwegian context. To move from pilots and promising initiatives to fully implemented solutions, the sector would benefit from a clearer, coordinated plan for industrial-scale implementation.

While the Norwegian railway sector does not lack initiatives and innovative ideas, it remains unclear how these can be translated into industrial-scale implementation and operational solutions. Key challenges include unclear arrangements for ownership, data access, financing mechanisms to drive investment, and liability across the asset life cycle.

At present, government investments are largely aligned with the National Transport Plan, which is focused on physical infrastructure. A notable digital transformation project in the NTP is the ERTMS investment programme, which represents the most impactful ongoing transformation in the sector. The programme previously targeted full national deployment by 2034, but a new study by the Norwegian Railway Directorate indicates in a scenario that the timeline may be extended to 2050-2060. When implemented ERTMS will reduce signalling failures and standardise trackside infrastructure and onboard signalling equipment. ERTMS will establish a foundation for future automation, including ATO, where ERTMS Level 3 and FRMCS are implemented. To accelerate digital transformation beyond ERTMS, there is a need for a clear government-led roadmap with well-defined objectives, governance structures, and stronger involvement from private industry. This includes the potential for targeted government-backed programmes that reduce investment risk, set clear outcome-based goals, and place conditions on actual production, deployment, and scaling of digital solutions.



1. Norwegian Ministry of Transport – National Transport Plan 2022–2033
2. Jernbanedirektoratet (2024): Randklev-bruddet kostet samfunnet 1,4 milliarder kroner
3. Bane NOR (2024): Re-planlegging av ERTMS – status og ny tidslinje for Norge
4. Anlegg (2026): https://anlegg.bygg.no/ertms-jernbane/nytt-signalsystem-kan-kroye-helt-til-2050/2944484

Collaboration and sector involvement

Collaboration is a key enabler for digital twin development. National innovation networks, research programmes, and pilot initiatives provide arenas for testing new technologies, sharing experience, and building competence across organisations. Progress is driven through cooperation between public authorities, infrastructure managers, operators, industry, and research institutions. The next step is to scale these initiatives into operations, which requires clarity on ownership, data access, investment and liability.

Several collaborative structures are particularly important, including the Arctic Test Arena addressing operations in harsh climates, national innovation networks for railway maintenance, and long-standing research cooperation with Norwegian and international research institutions. These arenas support applied research, data sharing, and early validation of digital twin concepts in real operational settings.

Through this collaborative ecosystem, the Norwegian railway sector combines public governance with private-sector expertise and research capacity.



Members of the Norwegian Railway Maintenance Network

1. Europe's Rail Joint Undertaking (2025): Europe's Rail Innovation Programme, including IAM4RAIL, R2DATO, TRANS4M-R, MOTIONAL and FutuRe
2. Norsk Regnesentral & Bane NOR (2025): AutoKontroll – Automated railway inspection using AI and train-mounted cameras
3. Jernbanedirektoratet (2026): Syv strategiske retninger for teknologi og innovasjon i jernbanen 2025–2030
4. Europe's Rail Joint Undertaking (2025): Rail Data Space
5. Jernbanedirektoratet (2026): Vedlikeholdsnettverket for jernbane

European alignment

Norwegian digital twin development is embedded in a European policy, regulatory and standardisation context. Through the EEA Agreement, Norway is aligned with EU railway and digitalisation frameworks, and Norwegian actors join European programmes and standard-setting bodies. This enables interoperability, funding access, reuse of solutions and scalability.

Norwegian stakeholders are engaged in EU-level research and innovation programmes, most notably through Europe's Rail Joint Undertaking and Horizon-financed R&D projects. These programmes provide co-funding, shared development of digital enablers, and early influence on future European architectures for data exchange, digital twins, and traffic management, while reducing duplication of effort through joint development with European partners.

Regulatory alignment is a critical dimension. The Norwegian railway sector follows EU legislation on interoperability, safety, and data exchange, including requirements related to ERTMS, harmonised technical specifications, and common operational rules. Digital twin initiatives must therefore support compliance with TSIs and evolving EU regulation on digitalisation, automation, and data sharing, reducing implementation risk and strengthening operational legitimacy.

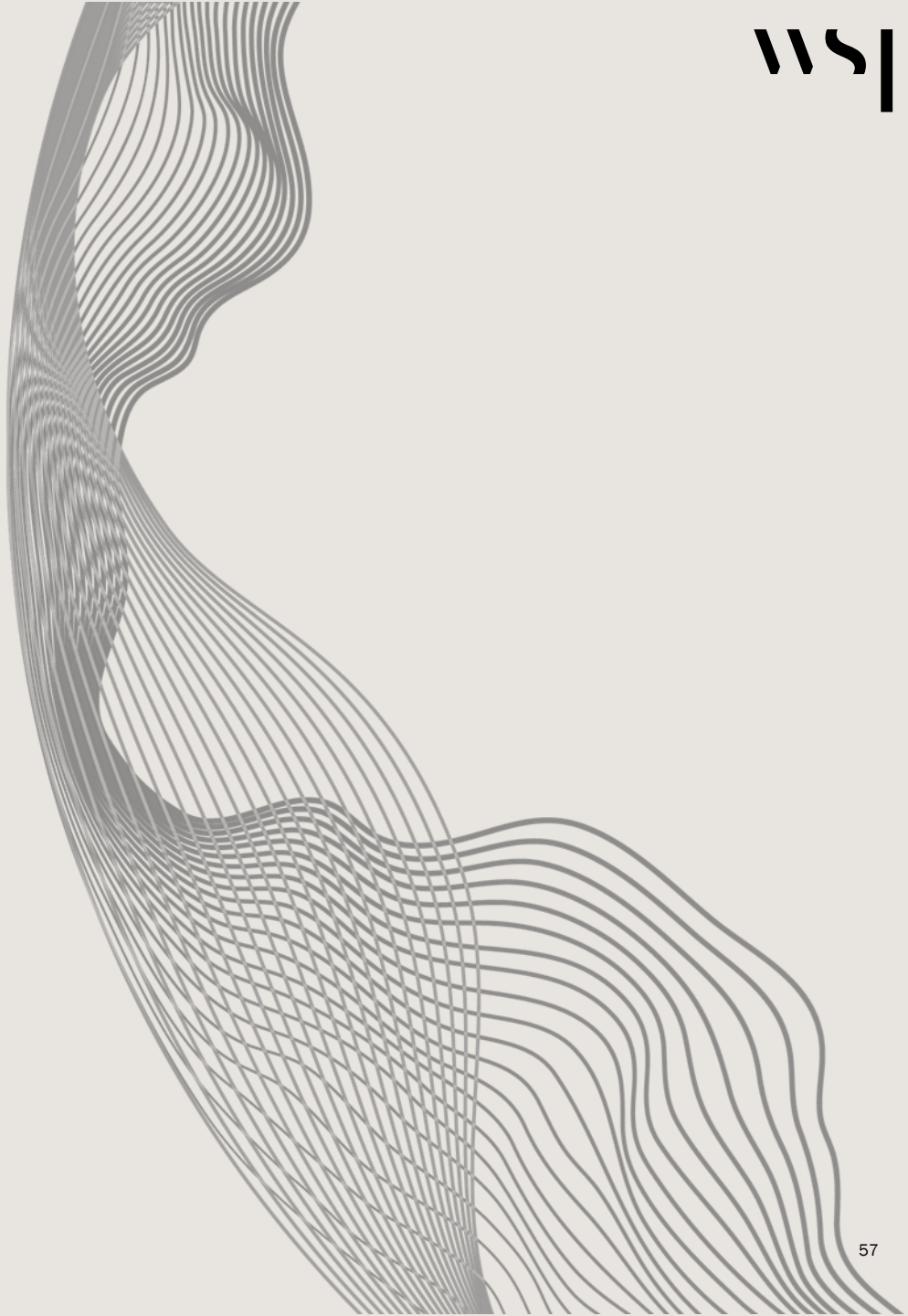
European data governance and standardisation frameworks further shape digital twin development. Initiatives such as the EU Data Act and European Common Data Spaces influence principles for data access, ownership, and trust, while converging standards for BIM, asset information management, data models, and interfaces improve interoperability and reduce vendor lock-in. Alignment with these frameworks positions Norwegian initiatives to participate in future European rail data spaces and scale digital twins across borders.



1. https://digital-strategy.ec.europa.eu/en/policies/data-spaces
2. European Commission (2026): Commission adopts harmonised EU specifications for data sharing in rail transport
3. European Union Agency for Railways (2026): European Commission adopts new TSI on telematics to enable interoperable data sharing in rail
4. Europe's Rail Joint Undertaking (2025): The Rail Data Space within Europe's Rail Joint Undertaking
5. International Data Spaces Association (2025): European Rail Data Space
6. European Commission (2024): Common European Data Spaces – Shaping Europe's digital future

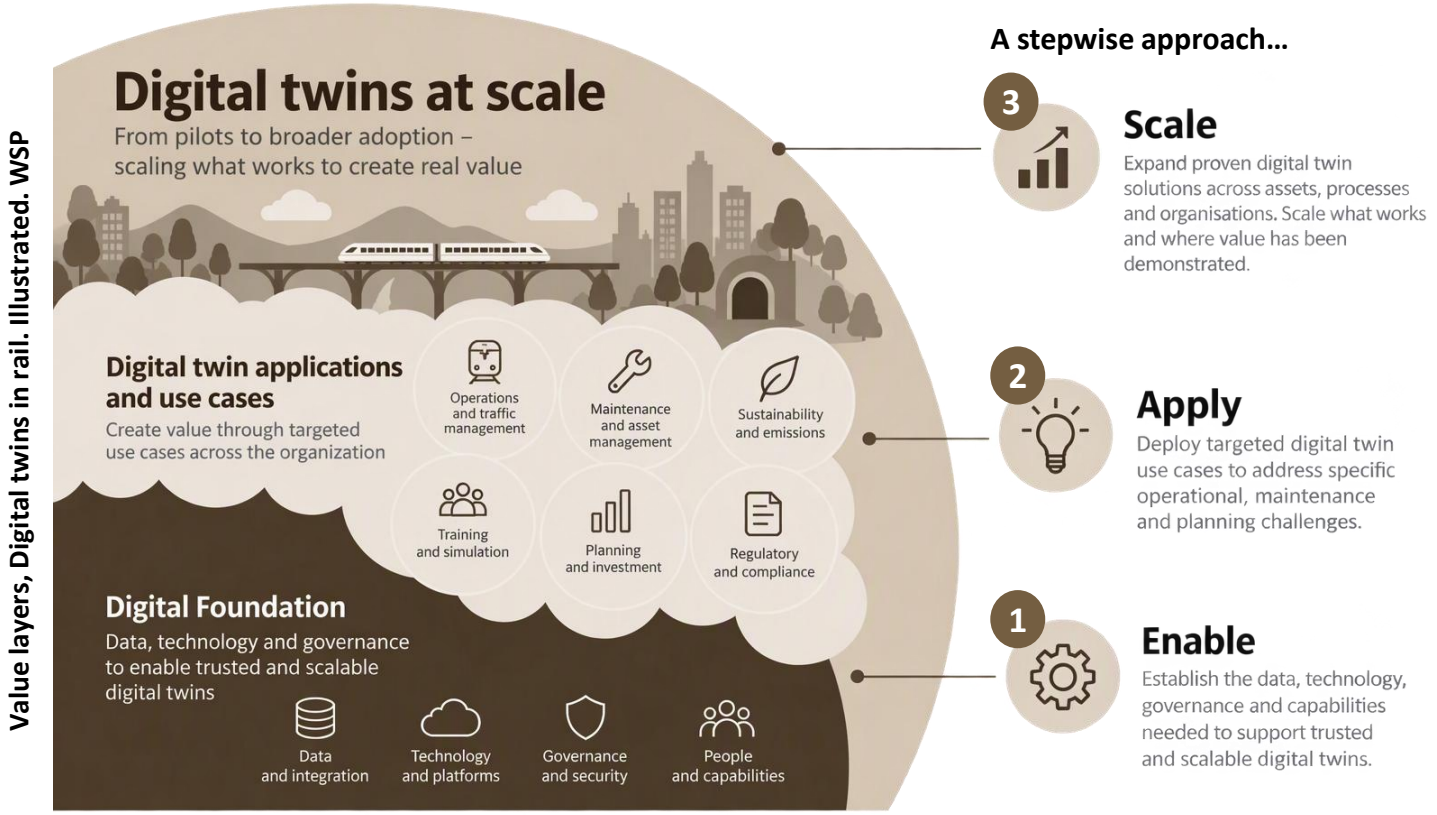
05

Strategic Assessment & Recommendations



Digital Twins in Railway | Unlocking Value

Digital twins unlock value in railways by connecting data, systems, and processes across the entire life cycle, enabling better decisions, improved efficiency, and more resilient operations.



A stepwise approach…

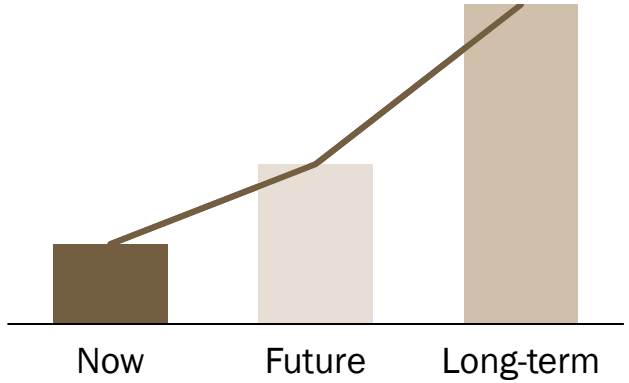
3 Scale
Expand proven digital twin solutions across assets, processes and organisations. Scale what works and where value has been demonstrated.

2 Apply
Deploy targeted digital twin use cases to address specific operational, maintenance and planning challenges.

1 Enable
Establish the data, technology, governance and capabilities needed to support trusted and scalable digital twins.

Railway digital twins, long-term potential

"Digital and AI-driven use cases in rail could unlock $13–22bn* annual value globally"
UIC & McKinsey



1. Department for Transport (UK, 2024): Integrated network management digital twin: economic benefits analysis
2. ORR: Rail Industry Finance (UK)
3. BCG (2025): The Route to a Fully Digitized Rail System
4. WSP Global (2026): *life cycle digital twins*
5. Global Railway Review (2024): *Leveraging Digital Twins in Rail*
6. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle. Bentley Systems eBook.
7. UIC & McKinsey (2024): The journey toward AI-enabled railway companies

Note: *To provide a sense of scale, full yearly cost of British railway was ~£11.1bn in 2025. Compared to the UIC & McKinsey yearly global estimate of ~£10–17bn. Calculated in British pounds.

Digital Twins in Railway | Value Propositions

Digital twins in railways create clear value propositions by turning data into actionable insights that improve performance, reduce costs, and enable more resilient operations.

By leveraging digital twins' applications and use cases the rail sector can improve key metrics providing better customer experience and value for money. The most important findings from Chapter 2 are summarised below.

Reliability and performance: This report's value assessment shows improved reliability through better asset utilisation, real-time insights and simulations that enable more informed and proactive decision-making. For today's railway reliability has emerged as one of the most important dimensions to improve.

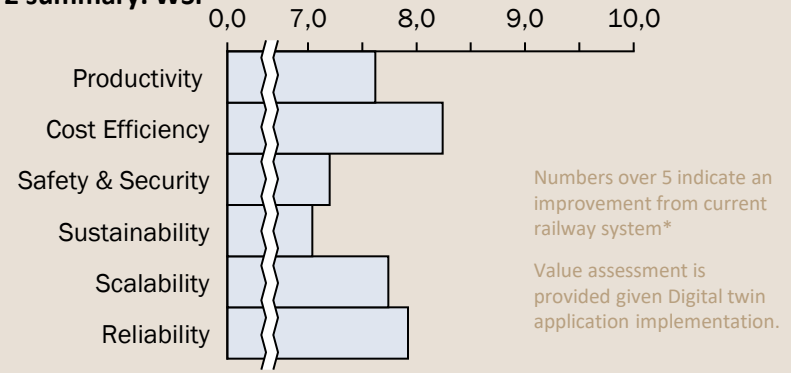
Cost efficiency: Cost efficiency comes out as the strongest contributor to value creation across digital twin applications for railway. Optimised operations and maintenance reduce downtime and resource use. Beyond the direct cost savings, reduced operating and maintenance costs create greater capacity for reinvestment in the railway system.

Enhancing productivity: Building on more autonomous systems and robotisation in all life cycles, productivity in railway will increase. Predictive capabilities lower life cycle costs and mitigate operational risks.

Digital twin application assessment, summary and key takeaways for Chapter 2. WSP

Application	Overall score	Highest value	Rail Economic Impact
1. Life cycle digital twin	7,5	Reliability	High
2. Railway digital testing	7,7	Cost efficiency	Medium
3. Railway predictive maintenance	7,8	Reliability	High
4. AI process automation in rail	7,4	Productivity	High
5. Digital training and operations	7,7	Cost efficiency	Low

Value propositions, key metrics, digital twins in railway. Chapter 2 summary. WSP



1. Europe's Rail Joint Undertaking (ERJU) – programme, deliverables and digital rail innovation
2. Shift2Rail / Europe's Rail (2019): Digital Twin demonstration
3. McKinsey: Digital twin concept and scaling
4. IBM (2026): Digital twin maturity model
5. WSP, Dassault Systèmes and Deutsche Bahn (2023): Enterprise Asset Management and Digitalization of Rail Systems
6. Digital Twin Consortium: The Business Maturity Model Is Key to Digital Twin Adoption

Norwegian Roadmap to Digital Twin Technology Adoption

Successful adoption of digital twins in the Norwegian railway sector requires coordinated development across multiple dimensions in parallel, as value is only realised when data, technology, use cases, and organisational capabilities are aligned. Norway is strong in technology and innovation, but weaker in the foundations required for scaling. Better data standards, clearer governance, and stronger implementation capabilities (foundations and adoption) are needed to move from isolated pilots to sector-wide adoption.

A strong digital foundation, ensuring high-quality, standardised, and integrated data, must be developed alongside scalable platforms and technologies enabling real-time processing, simulation, and analytics. At the same time, clearly defined applications and use cases are required to translate technical capabilities into measurable value. Focus should be on what is fit for scaling and high-value use cases. Clear KPIs should be established to guide testing, implementation, and value realisation. Equally important, organisational structures, governance models, and competencies must support adoption, ensuring that digital twins are embedded in decision-making and operational processes. Alignment across these pillars is critical, as gaps in one dimension will constrain progress in others and limit the overall impact. Models must be continuously validated against real-world data.

Digital twin roadmap dimensions, Norwegian railway sector. Key takeaways Chapter 3.

Foundations	Enablement	Application	Adoption
Data & standards	*Technology platforms*	*Use cases & Applications*	*Organisation & Governance*
• Data availability, quality, and standardisation • Asset models and digital representations • Data integration across systems (IT/OT) • Interoperability standards (BIM, rail standards, APIs) • Data governance (ownership, life cycle, access)	• Digital twin platforms and architecture • Simulation, analytics, and AI capabilities • Cloud, edge, and real-time data processing • Integration platforms and middleware • Cybersecurity and system resilience	• Using data, technology and organisation to test, prove and innovate digital twin technologies. • Life cycle coverage and system perspective • Maturity and scalability – create volume by prioritising • Integration in operations (adoption) • Value realisation (KPIs, business cases per use case)	• Operating model and processes (how twins are used in decisions) • Roles and competencies (skills, ownership of twins) • Change management and adoption • Governance structures and decision rights • Financial structure and incentives • Ecosystem and cross-sector collaboration

1. Bane NOR (2025): BIM and standardisation in railway infrastructure
2. Bane NOR / Government of Norway (2019): ERTMS – national railway digitalisation programme
3. European Union Agency for Railways (2024): Technical Specifications for Interoperability (TSI)
4. European Union Agency for Railways (2025): ERA Rail Data Ontology and data standardisation initiatives
5. Europe's Rail Joint Undertaking (2024): Digital twins and modular rail architecture (MOTIONAL programme)
6. Europe's Rail Joint Undertaking (2025): European Rail Data Space (ERDS)
7. Digital Twin Consortium (2021): Infrastructure Digital Twin Maturity Model

Scaling Potential and Coordinating Investments by Cross-Sector Alignment

Cross-sector alignment is essential to unlock the full scaling potential of digital twins in the railway sector. Many of the foundational components, such as data models, digital infrastructure, and analytical capabilities, are already being developed across adjacent sectors. Leveraging and better coordinating these initiatives will strengthen the overall digital ecosystem. In this context, Europe's Rail, related initiatives and cross-sector actors are key partners.

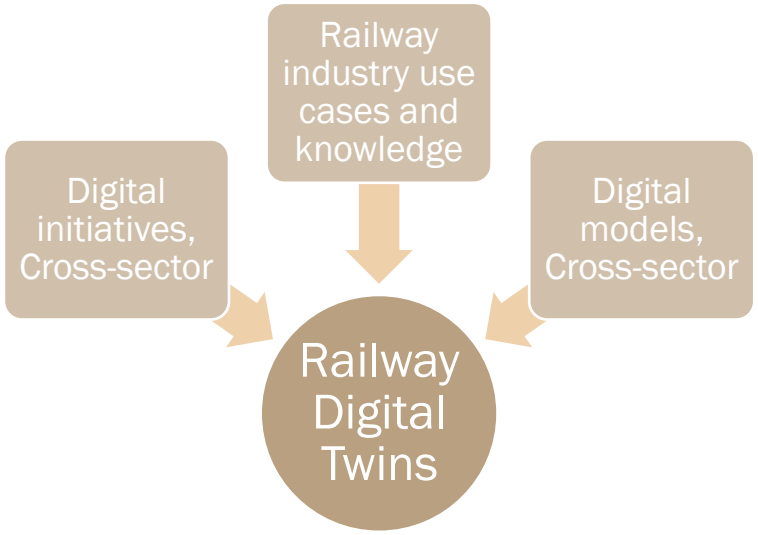
Coordinate digitalisation initiatives, models and investments

Many adjacent sectors are already establishing digital models and data foundations relevant to rail, including energy infrastructure (Statnett), geospatial platforms (GeoNorge), and urban digital twins developed by municipalities and transport authorities to name a few. Rail is also a critical logistics partner for defence, where major investments are being made in autonomy, drones, sensing technologies, and decision support.

Cross-sector alignment can create shared data foundations, improve interoperability, and accelerate scalable digital twin solutions. This requires stronger coordination through joint programmes, shared investment priorities, and common development frameworks. Such mechanisms can align stakeholders, coordinate funding, and help digital twin initiatives move beyond isolated pilots while reducing time, cost, and duplication of effort through the reuse of common digital foundations.

Leverage on knowledge and competence in the railway industry and Europe's rail network

Leveraging Europe's Rail initiatives enables the Norwegian railway sector to build on shared European research, data frameworks, and digital architectures—accelerating development, ensuring interoperability, and reducing the cost and risk of scaling digital twin solutions across borders.



Coordination with key partners and will help scale digital twin solutions for Norwegian railway

1. WSP Global (2026): Life cycle Digital Twins
2. Boston Consulting Group (2025): The Route to a Fully Digitized Rail System
3. UK Department for Transport (2024): Integrated Network Management Digital Twin: Economic Benefits Analysis
4. Global Railway Review (2024): Leveraging Digital Twins in Rail
5. Bentley Systems (2023): Digital Twins Drive Better Outcomes Across the Rail Asset life cycle
6. UIC & McKinsey (2024): The Journey Toward AI-Enabled Railway Companies

Recommended direction for Norway’s railway sector

Based on this report, WSP recommends four priorities for realising value from digital twin technology in Norway’s railway sector:

1. Scale proven solutions
2. Strengthen data foundations
3. Improve coordination and governance
4. Leverage Europe’s Rail and adjacent sectors

A strong starting point, but barriers to scaling

Norway has a strong portfolio of digital initiatives in rail, and the digital twin roadmap assessment shows strong performance in Applications & Use Cases and Technology Platforms, indicating a solid basis for further adoption.

However, Data & Standards and Organisation & Governance remain weaker. Fragmented responsibilities, unclear data ownership and limited implementation mechanisms leave many initiatives as pilots or isolated solutions. The challenge is to build on Norway’s technological strengths while strengthening the foundations for deployment at scale.

Need for a stronger focus on implementation

The four priorities address these barriers. The sector should prioritise the wider deployment of proven solutions, supported by shared data standards and clear ownership. Stronger coordination and governance should establish clear delivery responsibilities and common priorities across the sector.

Collaboration with Europe’s Rail and adjacent sectors should support this effort, drawing on relevant experience and existing initiatives. Together, these priorities can help move proven solutions into wider operational use and realise the value of digital twins and AI.



Illustration: Norway's new long-distance trains (Stadler)

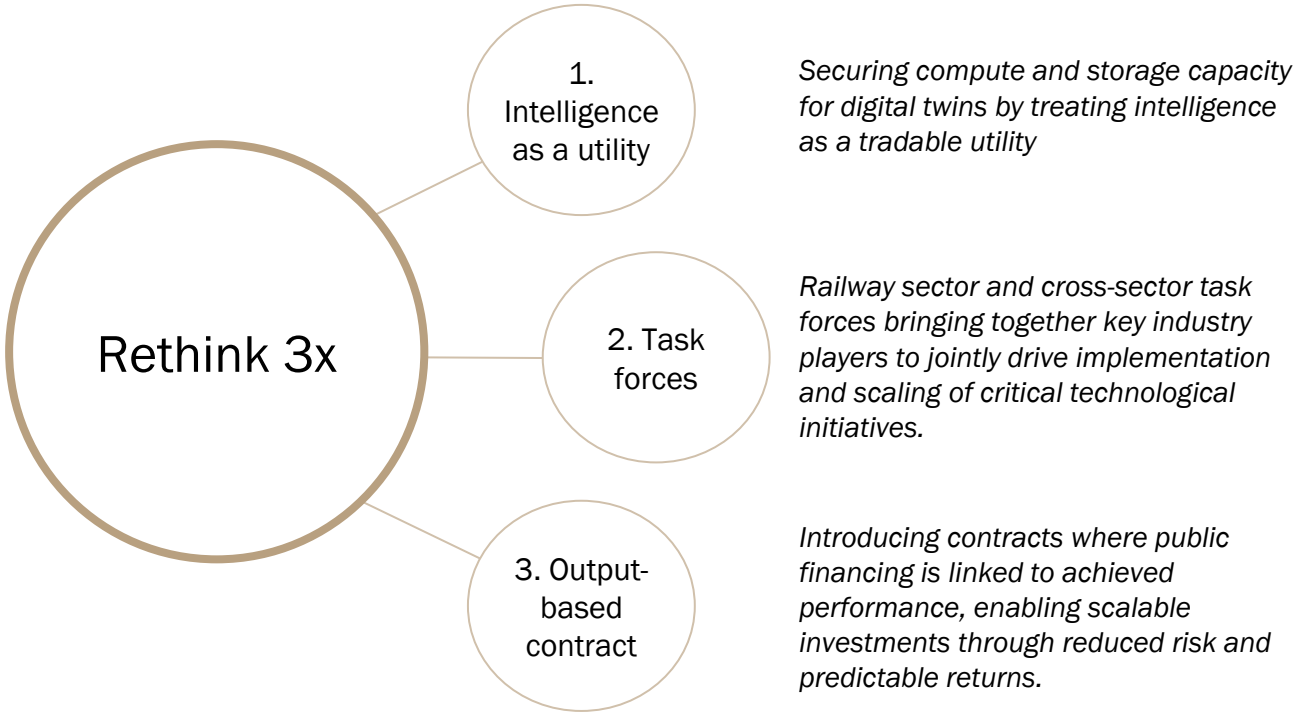
Rethink 3x | Beyond Digital Twins: Three ways to rethink the framework for technological development in Norwegian railway

The following slides present three ideas designed to challenge existing approaches and accelerate technology adoption, implementation, and innovation in the Norwegian railway sector. Through Rethink 3x, WSP contributes three perspectives intended to stimulate further discussion and exploration.

Norway's National Transport Plan highlights digitalisation and new technology as key enablers for a more efficient transport system. However, the Norwegian railway sector continues to face significant challenges related to reliability, cost overruns, project delays, and lengthy implementation cycles.

While the sector has launched numerous digital initiatives and pilot projects, translating innovation into large-scale operational deployment remains difficult.

WSPs Rethink 3x builds on the findings of this report, where the framework presents three ideas intended to challenge current approaches and stimulate debate on how the railway sector can accelerate technology adoption, implementation, and value creation. All three ideas should be explored further through dedicated investigations to assess their feasibility, define implementation models, and determine how they can best support the long-term development of the Norwegian railway sector.



Rethink 3.1 | Intelligence as a utility; securing computing and storage capacity for future digital twin solutions

Intelligence is increasingly emerging as a utility, similar to electricity or water, but with a premium. This shift requires a new approach to how such a utility is structured and procured. We see a need for a greater use of financial instruments and frameworks that can more effectively communicate government and private demand for long-term intelligence and computational capacity, moving beyond today's fragmented, bottom-up approach toward a faster, more efficient and scalable approach.

As shown in this report, intelligence, both human and AI, is fundamental for digital twins to reason, function and operate. With datacentres being built out on a massive scale the supply of AI as part of the intelligence market is growing.

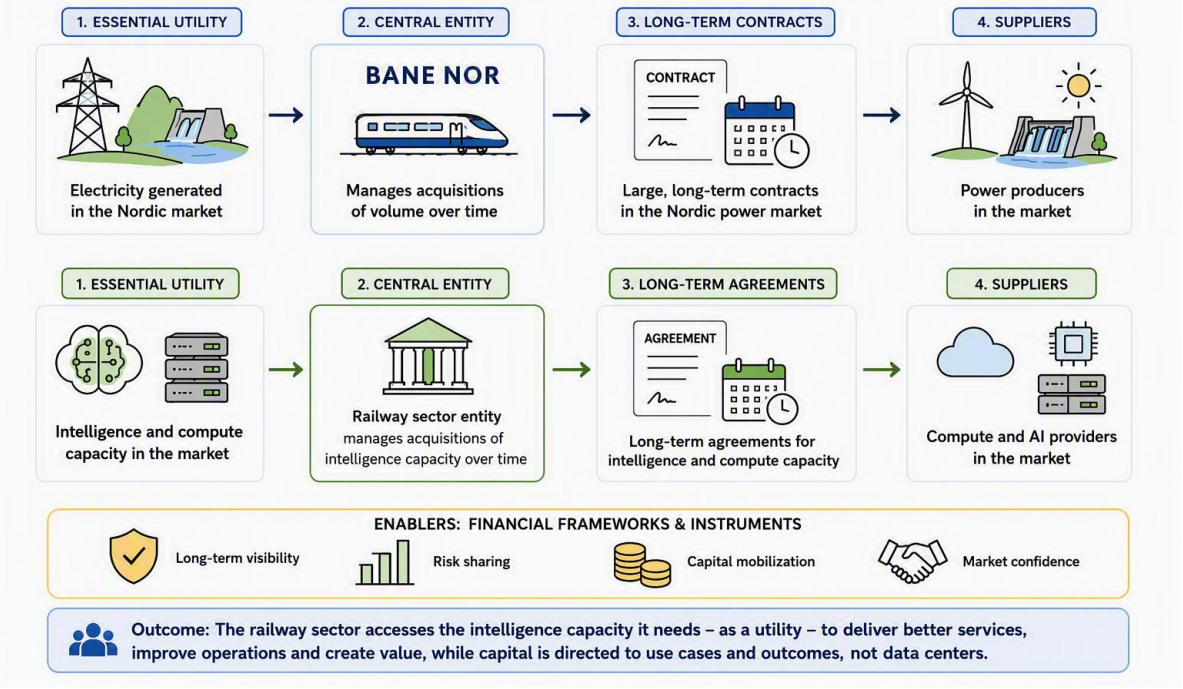
"We see a future where intelligence is a utility, like electricity or water, and people buy it from us on a meter"

Sam Altman, CEO OpenAI

Digital twins will require significant computing and storage capacity to operate securely and efficiently. Governments should treat these resources as critical utilities, similar to electricity and telecommunications. Financial instruments could provide an efficient and scalable way to communicate future demand to the market. NVIDIA proposed in August 2026 a framework that could form the basis of such a market.

The transport sector can learn from how the railway industry procures electricity through long-term contracts, applying similar mechanisms to secure the computing and storage capacity needed for future digital twins and automation solutions.

Rethink 3.1. illustrated. AI-generated image, concept and prompt by WSP



1. NVIDIA (2026): AI Factories as an Investable Asset Class
2. NVIDIA (2026): NVIDIA Partners With Apollo, BlackRock, Blackstone, Brookfield, Goldman Sachs and KKR to Establish AI Compute Infrastructure Financing Platforms
3. UIC & McKinsey (2024): The Journey Toward AI-Enabled Railway Companies
4. Boston Consulting Group (2025): The Route to a Fully Digitized Rail System
5. Europe's Rail Joint Undertaking (2025): Rail Data Space within Europe's Rail Joint Undertaking
6. Eress (2026): Partnership for European Railway Energy Settlement Systems
7. Bane NOR (2026): Strømforsyning

Rethink 3.2 | Railway Task Forces to Accelerate Technology Implementation

Technology implementation in the railway sector is often slow and costly due to fragmented responsibilities, complex governance, and limited mechanisms for scaling successful initiatives. WSP proposes establishing vertically integrated task forces that bring together the capabilities, authority, and resources required to implement prioritised technologies.

Today's publicly funded technology and innovation programmes tend to focus heavily on research, development, and pilot projects. While these initiatives generate valuable knowledge and promising solutions, the transition from successful pilots to industrial-scale implementation remains a critical gap.

WSP proposes establishing vertically organised task forces with a strong presence from industry and the private sector to accelerate the scaling of railway solutions. Task forces should be established with a clear mandate defined by key public authorities. Government companies and regulators must be present. The private sector is inherently focused on scalability and market relevance, ensuring that solutions are aligned with operational needs and can be deployed at scale. To our understanding such task forces would have the right tools to identify high-value initiatives, enable faster decision-making, reduce coordination overhead, and create conditions for scalable deployment. If successful, such an organisation could become a catalyst for greater vertical integration across the Norwegian railway sector.

«Task forces must be backed by dedicated resources, aligned incentives, and clear accountability for delivering measurable outcomes»

Rethink 3.2. Task force, illustrated. AI-generated image, concept and prompt by WSP



1. WSP (2026): Transportation AI field guide
2. European Commission (2024): EU Missions and Mission-Oriented Innovation
3. ERRAC (2020): Rail Strategic Research and Innovation Agenda (SRIA)
4. CECA, Railway Industry Association and Network Rail (2023): Delivering Enterprise models in the UK rail sector
5. Project 13, UK: About Project 13

Rethink 3.3 | Output-based contracts aiming for more performance-driven incentives in government support

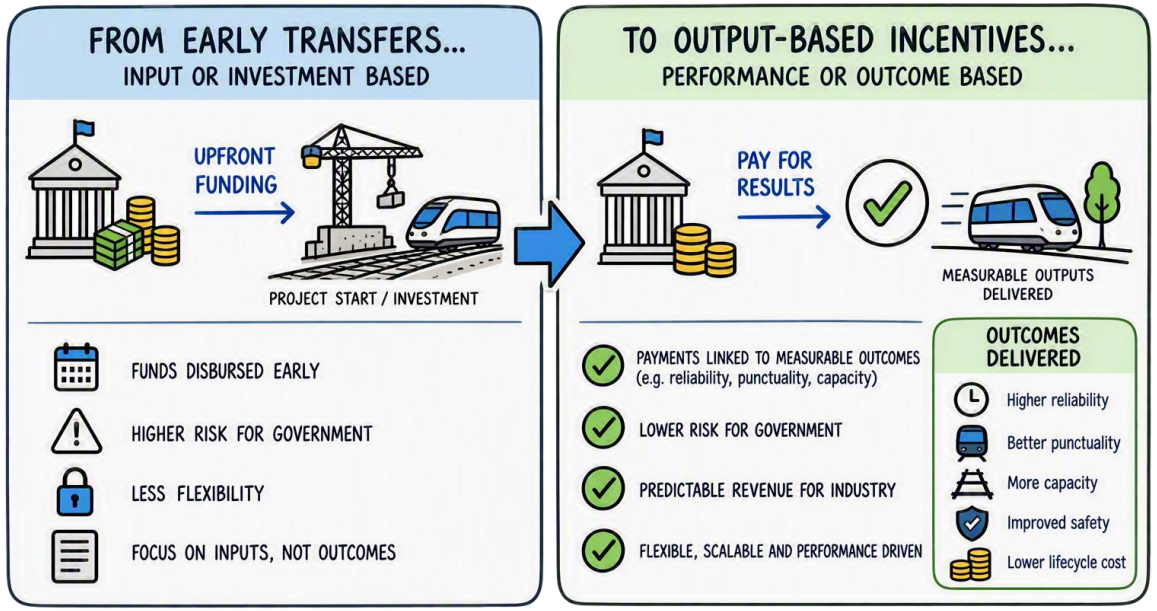
Public funding for rail should increasingly reward documented outcomes rather than primarily financing activities, pilots, or technology inputs. Output-based contracts link part of the compensation to predefined and independently verifiable results. This aligns public spending with societal value while giving delivery partners, whether public or private, flexibility to identify the most effective solutions.

While the task forces proposed in Rethink 3.2 establish shared delivery responsibility, output-based contracts provide the financial incentives needed to align participants around measurable railway improvements.

Traditional funding models (such as NTP in Norway) often pay for resources, equipment, development activities, or delivery milestones, regardless of whether the investment ultimately improves railway performance. The Norwegian railway sector consists of specialised entities across the value chain, but lacks performance incentives which in our view limits collaboration, implementation and scaling, and ultimately limits the prioritisation of projects that improve railway performance.

An output-based approach would reward improvements in key metrics. Incentives should span the entire value chain, not only customer-facing organisations. A combination of fixed funding and performance-based payments could balance delivery certainty with incentives for measurable improvement. Successful implementation requires clear KPIs, reliable baseline data, transparent verification methods and balanced risk-sharing between public authorities and delivery partners. Similar principles can be seen in production-based support schemes, where financial support is linked to verified results rather than investment expenditure alone.

Rethink 3.3. illustrated. AI-generated image, concept and prompt by WSP



1. U.S. Environmental Protection Agency (2026): Summary of Inflation Reduction Act Provisions Related to Renewable Energy
2. European Investment Bank (EIB): Outcome-based financing and impact investing
3. Internal Revenue Service (2026): Clean Electricity Production Credit
4. Europe's Rail (2025): Innovation Programme Governance and Deployment
5. Social Finance UK (2024): Outcomes-Based Contracting
6. U.S. Bureau of Justice Assistance (2026): Pay for Success Overview

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Jernbane-
direktoratet
Norwegian Railway Directorate

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Railway use cases and ways to enhance an asset-heavy sector

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