Delivering Intelligent Integrated Digital Rail Systems and Operations & Maintenance

Early project adoption of integrated data-driven digital design is key to bringing high returns for operations and maintenance.

This whitepaper was developed by WSP in collaboration with DB International Operations and Dassault Systèmes.

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Early adoption of intelligent digital delivery is essential to lay the foundation for a successful rail operations and maintenance phase (O&M)—both for new transit systems and legacy systems planned for expansion or modernization. Various digital technologies are successfully employed today to improve the planning, design, construction and commissioning phases (development) and O&M phases of new or improved transit systems. These capabilities, however, typically focus on each phase and/or each participant to improve the productivity and quality of the deliverables produced therein or thereby accordingly. The overall performance of transit system projects can be distilled into three fundamental criteria:

- Cost to deliver the transit system in an operational condition.
- Time to deliver the transit system in an operational condition.
- Discrete performance[1] of the transit system in its operational condition.

A common data environment and an integrated information model support the engineering and construction stages using model-based system-of-systems engineering (MBSoS),[2] providing a comprehensive 360-degree view of the critical requirements and allowing modelling and simulation to ensure a quality design for construction and O&M. The full value of progressively building an integrated information model during the engineering and construction phases will be realized using the as-built virtual twin of the transit system during the O&M phase. A virtual twin is based on an intelligent digital replica of a physical asset, including processes and systems, with continuously enriched field data. This twin is supported by multiple teams to enable highly reliable and safe rail services using digital asset management and predictive maintenance methods based on modelling and data-driven decision-making. Combining digital asset management, virtual simulation capabilities and data sourced from real-time operational data creates an intelligent digital rail system.

Integrated Delivery Team

To achieve the best decisions for the project, it is essential to deploy at the early stage, typically during the design, an integrated project delivery team including the key actors related to the asset lifecycle; these include engineers, planners and designers as well as construction and O&M partners—all will contribute to the best possible design and outcomes, and, as a collaborative team, carry forward lessons learned through the virtual twin. The virtual twin includes essential considerations that can later be leveraged to support commissioning, operations and maintenance of the rail assets.

A key element of the overall strategy is systems integration, which can be easily understood through WSP's SI:D[3] approach. To enable thorough visibility and effective decision-making throughout the lifecycle of rail projects, SI:D[3] focuses on smoothly integrating multiple subsystems, technologies and data into a single system that eventually improves engineering, construction, and O&M stages.

Intelligent digital delivery emphasizes the importance of modern digital tools as well as collaboration among designers, engineers, operators and maintainers to align on the scope and objectives of the virtual twin in a rail project. A common data environment (CDE) simplifies the way that information is managed, shared, accessed and stored through standardization of data formats. Easily accessing accurate information about the project encourages cross-communication and eliminates silos traditionally seen in complex infrastructure projects.

1 Transit system "discrete performance" includes but is not limited to availability, financial performance, consumer experience, environmental impact and sustainability, asset utilization, refit, repurpose, retire & recycle.

2 Model-based system of systems (MBSoS) capabilities are typically utilized to model assets such as the physical transit system. Such capabilities can also be utilized to model different characteristics or layers of the program engaged to deliver and then operate the transit system, to yield significant additional benefit.

Integrated Information Model

During the engineering stage, the integrated information model framework—which includes multidisciplinary digital models, integrated simulations and data-driven decision-making strategies—optimizes outcomes in each engineering discipline to support construction with fewer surprises and potential errors such that O&M phases can be successfully commissioned at start-up of the new rail services. The complete lifecycle of the project, O&M and asset health are supported through a cloud collaborative platform to bring faster data insights, alerts for deviations from normal conditions, and safer and more sustainable operations and maintenance. Using an intelligent digital approach allows decision-makers to test multiple scenarios and simulate new scenarios to determine and validate the best parameters to deliver optimum performance, cost, and risk balance.

Advancing Beyond Traditional BIM Modelling

The virtual twin approach is an advancement beyond traditional BIM modelling to facilitate 3D design validation, coordination, and 4D schedule planning with the potential for finer fidelity beyond schedule and budget to maximize value for money, whole lifecycle costing and ESG.

Construction Safety Enhancement

Using the virtual twin, construction crews can simulate multiple scenarios and evaluate the best plan for construction and commissioning sequences to enable a higher level of safety awareness on the job site.

Lifecycle

Typically, the lifecycle of a railway requires 3-5 years for planning and engineering and 2-10 years for construction, with O&M occurring over the life of the assets for 20-40 years. Therefore, the lifecycle period for the O&M stage drives the overall financial viability of the investment, alongside ridership growth, reliability, safety, lifecycle costs and net zero targets. Making better design decisions earlier in the lifecycle can benefit owners and operators for many years and result in fewer changes after system commissioning.

TYPICAL RAIL PROJECT LIFECYCLE

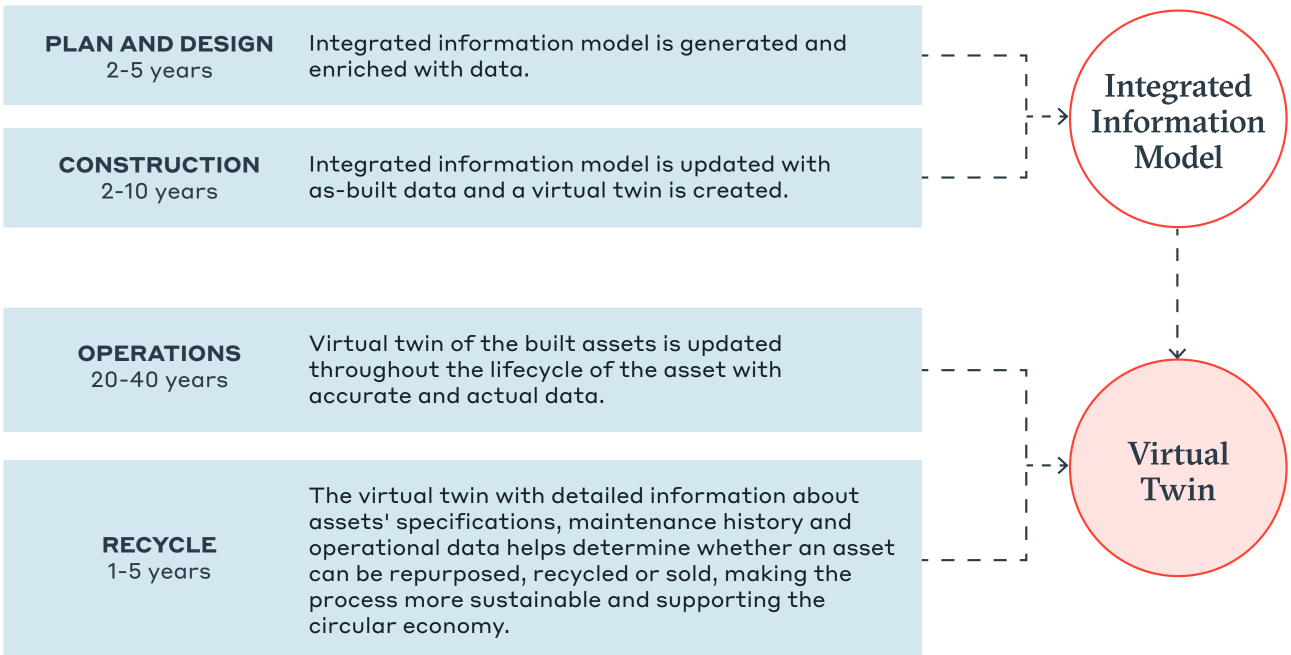

Figure 1 – Typical rail project lifecycle with integrated information model and virtual twin approach

The O&M phase of a rail project's lifecycle typically spans the longest duration and is also the most critical one. As rail systems become more complex, digital and technology-driven, there is a growing need for effective O&M services to ensure rail equipment runs smoothly and efficiently throughout the entire system lifecycle with minimum downtime and interruptions. To meet demand, rail systems must be maintained and operated efficiently, reliably and safely, to ensure that they can provide the required capacity. To bring optimal affordability, the design must reflect the complex needs for the construction phase and incorporate O&M knowledge for the ongoing operation of the rail system.

The transit system operators of today rely on clear visibility for all assets involved with the rail system. Digital delivery enables a deep understanding of where failures may occur, identification of system vulnerabilities and proactive measures to prevent service interruption.

Bringing Positive Change

Practice Today

In modern project delivery framework, design is done in 3D with metadata that supports construction sequences (4D), cost estimation (5D), asset information management, ESG information and health and safety—with appropriate key performance indicators. The integrated information model consolidates the vast amount of data inputs involved in railway systems and integrates the information into a CDE so that all members of the integrated project team can view the rail infrastructure before it is built. In most cases, the 3D integrated information model is kept as a record and may or may not be updated by the contractor with as-built information, depending on the nature of the contract. In a typical rail project where the P3 approach has been applied, the stakeholders engaged in the early stages have not traditionally included the O&M teams (as shown in Figure 2). This creates a major gap because operators are disconnected from the process of setting requirements, standards and procedures for the development of the railway design and integrated information model; their critical knowledge of operational challenges is not incorporated into the engineering and construction phases.

Collaborative Approach Creates Maintenance-Friendly Assets

A system-of-systems virtual twin framework approach will facilitate the design of maintenance-friendly assets, meaning that although the initial procurement costs may be higher they will be more economical in the long-term. From the planning phase through the engineering, construction, commissioning and operating phases, a cloud collaborative platform will enable the testing of multiple scenarios to identify the optimum performance, cost, safety, ESG, and risk balance to deliver affordable services.

With the integrated project team approach and critical data embedded within the virtual twin, the project design and planning stages can be leveraged for running O&M simulations to assist the operators in their maintenance activities. The operators will spell out their needs and challenges for effective operations and maintenance, every decision will be tailored around that need and the right workflows, and methodologies and procedures will be set. Having the operator's requirements integrated in the mature virtual twin makes the virtual twin intelligent and connected to system feedback—usable throughout the lifecycle of the rail systems. The operator's engagement during the setup phase of the project with clearly outlined requirements will maximize the potential of the virtual twin to support delivery of the targeted outcomes in a standard project.

The integrated project team shares common goals and objectives with individual stakeholders: the owners, engineers, constructors, and O&M teams. With common objectives in mind, the operational environment of the virtual twin supports data-driven decision-making for the entire lifecycle of the rail systems.

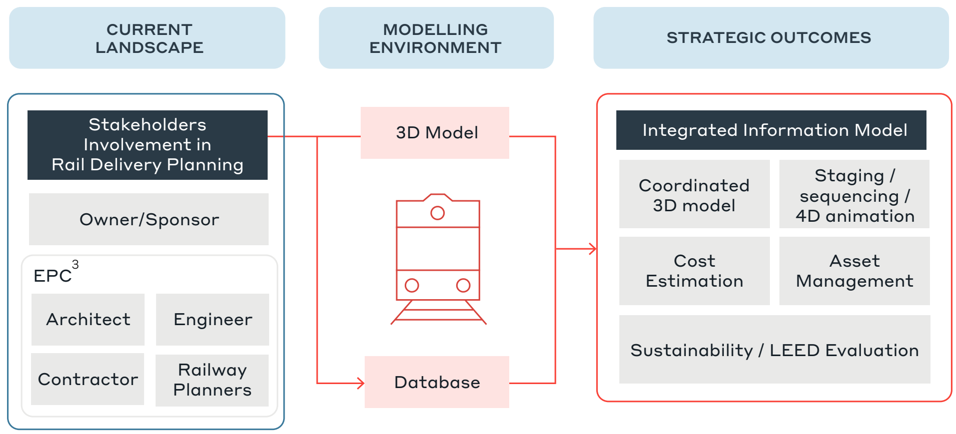

Figure 2 - Typical rail project delivery framework with minimum stakeholder engagement

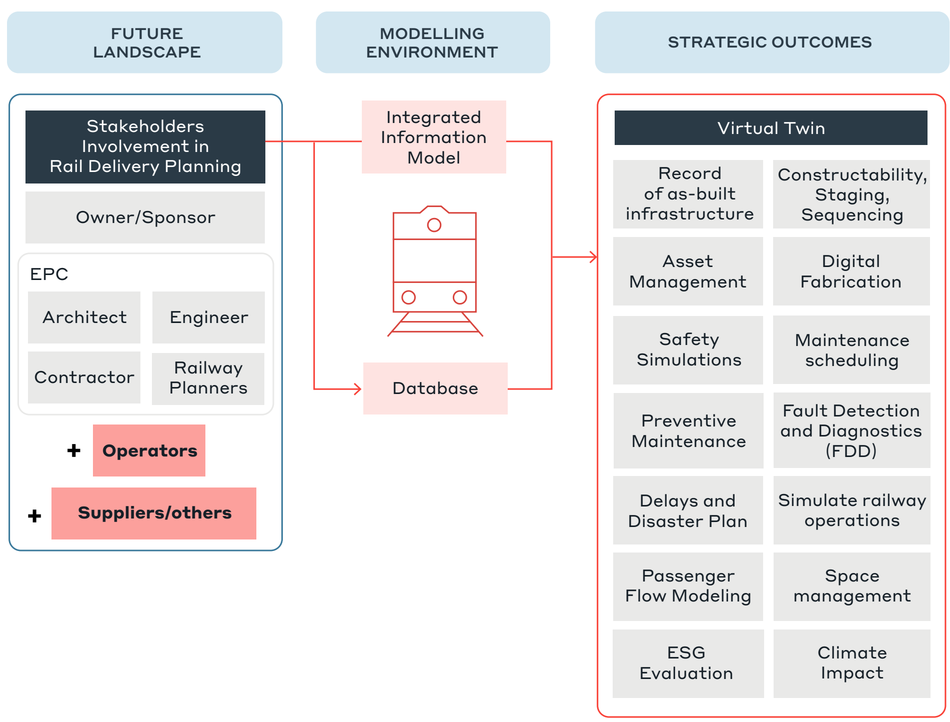

Figure 3 - Future landscape with rail O&M team and supplier engagement through a virtual twin

3 EPC stands for engineering, procurement and construction, a type of turnkey contract used to undertake construction works by the private sector on large-scale and complex infrastructure projects.

Virtual Twin

One of the key sources of added value provided by a virtual twin is its ability to interact with the physical system and automate certain activities. This interaction enables the virtual twin to go beyond being a mere replica or visualization tool and become an active participant in the rail system's operations and maintenance. For instance, as part of a predictive maintenance concept, the virtual twin can leverage real-time data from sensors and monitoring systems to analyze the condition of critical components and predict potential failures or maintenance needs. By automating the process of detecting and predicting maintenance requirements, the virtual twin enhances the efficiency and effectiveness of maintenance activities, reducing downtime and optimizing the use of resources. This integration of automation and predictive capabilities within the virtual twin contributes to improving the overall reliability, performance and cost-effectiveness of the rail system.

Diverse Benefits

Rail operators are primary beneficiaries, among other project stakeholders, of virtual twins through the entire system lifecycle. The virtual twins and technology—with high-accuracy data—can deliver diverse improvements:

- **Safety:** The virtual twin can highlight field work plans to demonstrate easy-to-understand procedures to avoid accidents, injuries, unexpected costs and project delays during construction. Through virtual simulations, workers can train before going to the jobsite, enabling them to plan for their work conditions with elevated situational awareness. Virtual twins support the creation of safety management videos, which can be used for training new and experienced personnel.

- **Constructability:** Apply deep knowledge for design and construction so that the integrated information model will support contractors with 3D visualization — to plan complex interfaces and optimize construction sequencing to minimize extra handling for faster project delivery. The construction work breakdown structure can be simulated and optimized based on several iterations and input from team members. The integrated information model can highlight constructability difficulties before they arise in the field, resulting in more timely, safe and economical construction.

- **Maintainability:** The virtual twin can be used to analyze maintenance requirements and model various options based on predictive maintenance solutions, leveraging data analytics and machine learning to identify potential issues and develop targeted maintenance strategies with the operators to improve service reliability.

- **Affordability and Accessibility:** The virtual twin models are populated with bill-of-materials information including cost, quantities, and supply-chain data and specifications. This enables simulations and options to be analyzed through various iterations depending on the requirements for speed of delivery, quality, reliability, ease of maintenance, durability, safety and sustainability. Providing cost-efficient solutions for ongoing O&M begins at the design and engineering stage to ensure lowest costs and highest reliability for the entire lifecycle of all assets.

- **Sustainability:** is a key factor in improving support for the rail industry. System electrification can play a major role in reducing the environmental impact of rail systems. The digital approach enables the simulation of the CO_2 emissions savings and the modelling of various options such as energy-efficient maintenance practices and the use of renewable energy sources.

- **Reliability:** Increased equipment reliability can be achieved through modern tools such as data analytics, predictive maintenance for preventing down times before they occur, and machine learning fault detection and diagnostics to support a data-driven decision-making approach for more effective and lower-cost maintenance practices. Reliability, safety and end user experience improves through the virtual twin implementation using a digital asset management platform. The built environment can be maintained in the virtual twin with ongoing updates to keep it as an accurate replica of the physical assets in operation.

- **Technology:** A virtual twin can enhance the user experience by enabling proactive response to common commuter complaints regarding, for example, the number of HVAC units, washrooms, WIFI, out-of-service visual display and faulty people movers.

It is crucial to conduct a thorough cost-benefit analysis to determine the fidelity of a virtual twin in specific scenarios as the maturity of the virtual twin will depend on the complexity of the project. It is essential to take a holistic view and identify the interfaces where a virtual twin can provide value and where other solutions may be more effective and cost-efficient. By carefully evaluating the specific requirements and considering the cost-effectiveness of different approaches, railway companies can make informed decisions about the adoption of virtual twins or alternative smart solutions to achieve their desired outcomes. The virtual twin should be designed and developed in a way that addresses the unique requirements and challenges faced by owners, operators and maintainers at different stages of the rail system's lifecycle. This includes incorporating the data, models and simulation capabilities that provide valuable insights and support decision-making processes in real-time. By tailoring the virtual twin to the specific needs of users and aligning it with their use cases, it becomes a powerful tool that enhances efficiency, effectiveness and overall performance throughout the entire lifecycle of the rail system.

VALUES PRODUCED BY VIRTUAL TWINS

- Parallel Work by multiple teams
- Accelerate Maturation
- Capture Deviation & Waivers
- Reduce Change Orders
- Manage Interfaces Between Parties
- Manage Interfaces Between Design Elements
- Manage Dependencies & Traceability from Mission – Requirements – Design – Construction – Operation

– Virtual twin as a service provides a higher fidelity operational state.

– Operations safety modelling to minimize lost time and improve safety.

– Data science and analytics - Information dashboards and data-driven decision support deliver better outcomes.

Key Recommendations

An integrated project delivery or the progressive P3 model combined with virtual twin adoption can deliver a SMART railway operation as highlighted in Figure 4.

S — Safe & Sustainable

Improve safety by identifying potential hazards, testing safety measures and optimizing energy efficiency to achieve net zero within the virtual twin.

M — Maintainable

Leveraging a virtual twin to simulate rail assets to predict potential failures before they occur, enabling operators to perform maintenance proactively.

A — Affordable & Accessible

Using the virtual twin to simulate different scenarios and identify the most cost-effective solutions, to reduce expenses and make rail transportation more affordable.

R — Reliable

Validating rail operations with efficient planning and coordination to improve constructability and deliver reliable services.

T — Technology

Leveraging the integrated information model, the virtual twin and data sensors, rail operators can optimize the performance of assets, reduce operational carbon emissions and embodied carbon,[4] increase reliability and safety, and improve the passenger experience.

Figure 4 – SMART Railway System O&M

4 Embodied carbon, according to the Structural Engineering Institute, is the sum of greenhouse gas emissions released during the following life-cycle stages: raw material extraction, transportation, manufacturing, construction, maintenance, renovation, and end-of-life for a product or system.

Conclusion

Several enablers guide WSP's efforts to help decision-makers in rail operations and maintenance: leadership, market drivers and investment in pilots to demonstrate viable solutions.

Transit owners and operators have a significant opportunity to mandate project delivery through cross-collaboration between the entire project team, such as through the integrated project delivery or progressive P3 models. The entire team can bring insights and valuable lessons learned to enable optimal O&M solutions for rail systems, leveraging their specialized expertise and experience in the design and construction phases of rail projects. With the growing demand for rail travel, the need for specialized expertise, the importance of safety, the potential for cost savings, and the importance of ESG and net zero mandates, there is a strong business case for project owners to integrate O&M services requirements early into the new railway systems. Early involvement between the operators, designer and contractors is key to intelligent digital delivery, which can set up success for rail operations and maintenance in an affordable manner.

Chris Harman, Vice President and Director of Digital Delivery and Innovation, WSP USA: "***Prior to adopting an integrated information model approach to break down all the silos, the chronological nature of procuring consultants and contractors in design, construction, and operations meant that we couldn't obtain input from the right people until their phase had begun, at which point it was too late. By modernizing contracting and procurement methods with an integrated information model approach, we can fully understand the operational requirements of a project before operations have begun—to be more cost-efficient from the beginning and deliver the expected outcomes.***"

As time goes on, we see labour and technical skills shortages for the built environment. Using the virtual twin during lifecycle management stages, people can be trained in a virtual realm before going to work in the field of the physical equipment and live operations, thereby improving safety of day-to-day rail services. When implemented with a strategic and long-term view, a data-driven digitally-enabled railway that can predict its own faults and prevent them from happening will build a positive end user experience while supporting long-term system viability and sustainability through electrification[5] of the rail system. By enabling effective collaboration and the right balance, a virtual twin can deliver efficient, reliable and cost-effective rail systems for all stakeholders throughout the system lifecycle.

Leadership

- Integrated Project Team
- Collaboration Platform
- Strategy
- Value for Money

The Integrated Information Model

- Progressive Procurement Model
- Standards methods & procedures
- Common Data Standards (ISO 19650)
- Digital Delivery

Virtual Twin

- Operation & Maintenance (O&M)
- Asset Performance Management (Digital)
- Whole Lifecycle Optimization (WLC)

Figure 4 – Intelligent rail system enablers

Related Reading: Enterprise Asset Management and Digitalization of Rail Systems

5 Shifting to electrification from diesel supports decarbonization, especially when including renewable sources for electrification.

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