Digitalization Optimizes Systems Integration of Rail Services

Establishing interoperability between new services and existing services for fully functional railway networks

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

June 5, 2024

TABLE OF CONTENTS

Backdrop

New rail networks offer significant benefits for communities and the people they serve. It takes vision, commitment and investment to build new infrastructure and years of planning to deliver services that meet the needs of commuters, operators and the public.

Rail systems support safer mobility and reduced road congestion as well as more efficient use of time. They can help create a better quality of life for people through convenient and inclusive access and reliable journeys to destinations. Rail networks advance positive health and environmental outcomes and economic vitality. Rail is also a means to support affordable housing and access to services needed for everyday living, such as through transit-oriented development around rail and/or bus stations.

In a world where urbanization is increasing, railways can improve connectivity between cities and regions. Rail continues to serve as the transport backbone in communities as they shift to more environmentally friendly and energy-efficient modes within mobility landscapes that accommodate more walking and cycling.

Rail networks continue to roll out globally; passenger and freight activity is expected to more than double by 2050.[1] More than CAD 2 trillion has been committed to rail projects underway around the world.[2] Due to long construction cycles, the start-up phases must be planned and well orchestrated; many systems and subsystems must work in a synchronized manner to offer safe and reliable passage for riders.

The Role of Digitalization

When extending or developing rail systems, digitalization becomes essential due to the increasing demands and complexity of systems as new technology is adopted and passenger expectations grow. Digitalization is a means to effectively integrate the elements of rail systems and to support integrated multimodal transport services.

A combination of digital tools enables a common view of system of systems—during the developmental stages and operation—to support safety, reliability and maintainability for rail operators, rail owners and the travelling public. Digitalization can also support cost-effectiveness through predictive maintenance based on data-driven decision-making.

Overall, digitalization is key to enabling early planning, collaboration and intervention to prevent problems. It also optimizes efforts toward delivering targeted outcomes in the areas of safety, operational quality and availability of services. Applying a systems integration (SI) approach helps project stakeholders navigate complexity to understand and effectively coordinate the systems toward optimal functionality. SI manages the vast amount of information, the coordination of systems and the stakeholders involved.[3]

Over the next decade, many rail networks will be built globally, and, like any major project, detailed orchestration during start-up phases will be paramount to enable the proper execution of the works. A railway project comprises multiple systems and components throughout the asset lifecycle, installed in diverse environments in a linear or localized configuration (tunnel, bridge, at grade).

1 The Future of Rail, iea50, January 2019.

2 CAD 2 trillion represents a combination of figures from government sources and technical journals, compiled by WSP.

3 Systems Integration, WSP. WSP's SI:D³ framework uses proven systems engineering techniques to connect technical management with established program management processes.

Guiding Goals

Six goals serve as guiding principles during the early stages of project design through implementation; they are critical to the success of major rail projects that seek to bring benefits for customers, owners, operators and other stakeholders.

The figure below shows the progression of targeted outcomes based on integrating existing rail services with new systems.

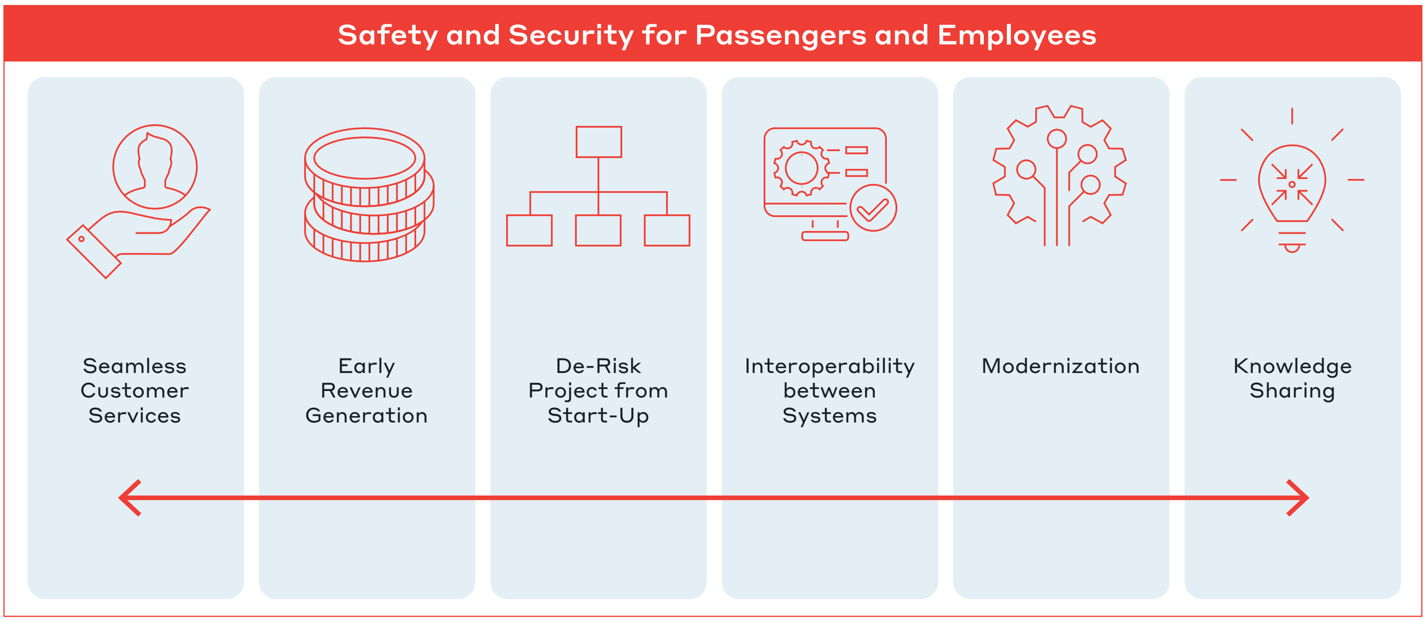


Figure 1 – Six goals to guide systems integration when expanding rail systems

When introduced early in project development, these goals drive project focus among competing priorities, facilitate shared understanding throughout the project and maintain project stability toward targeted outcomes.

Seamless Customer Services

Deliver a Positive Customer Experience

Why

- Attract riders
- Reliable journeys
- Ticketing convenience
- Better accessibility
- Build public confidence
- Wayfinding and smooth last mile
- Convenience over other modes of transport

How

- Emphasis on safety
- Define requirements early
- Pre-planning journey
- Design focus on rail performances
- Computer-aided simulation models
- Identify and correct errors before start-up
- Affordability

There are numerous interfaces for railway passengers and operators—passenger ticketing systems, door systems for entry and exit to the trains, wayfinding, interactive maps, schedule information systems, links to other transit services, last-mile options and parking for passengers. These services and touchpoints must be carefully planned and pre-tested to consider accessibility and other targeted outcomes, and to make sure such targeted outcomes are achieved. As with any commercial service, rail passengers have high expectations. From ticketing to the end of trip, travellers must be guided to experience smooth journeys.

Defining requirements early in the planning and design phases through SI, to extend through to operation, strengthens customer interfaces toward convenient, frictionless and reliable travel. As passengers experience this outcome, ridership confidence should increase, translating into higher adoption rates and wider usage. Implementing more accessible operations, as well as improving affordability—another key factor to encourage more people to favour rail services—will also translate into higher ridership levels, thereby resulting in less CO_2 emissions to support positive health and environmental outcomes.

Initiated early in a project, digitalization and SI support and advance these desired community outcomes.

Technical Considerations

From an engineering perspective, to deliver the best outcomes for optimum customer experiences, each interface must be simulated in a model that is easy for designers to understand. A common modelling language (the systems modelling language, SysML), facilitates the modelling of components in their respective environment, highlighting their interfaces with other components and the associated interactions. All team members, can thereby develop models for their scope package in a consistent, collaborative manner, permitting a preliminary integration during design stages rather than leaving siloed systems that must be merged after design and during construction. This approach leads to a positive domino effect across the various subsystems in addition to preventing undesired and unforeseen border effects on external systems and assets.

Early revenue generation

Applying System Simulation

Why	How
• Large capital investment	• Systems Integration Lab (See Figure 2)
• New service availability	• Progressive start-ups for operations and mtce
• Pay back financiers	• Open standards
• Eliminate project delays	• Reverse engineer from end goals
• Build public confidence	• Iterative and incremental approach
• Facilitate future financing for rail projects	• Simulation tools for factory acceptance tests
• Incremental skills development	• Virtual Twin for initial training (Operations teams)

Large capital investments are required for new railway infrastructure and expansions. Progressive start-ups of smaller segments can generate early revenue rather than waiting for the entire network to be commissioned. This approach can also help to obtain financing for future rail infrastructure projects. In parallel, progressive start-ups help to engage the public to support future projects by demonstrating that wider project objectives can be achieved. The financing costs of the public transport systems will decrease as projects are delivered progressively and revenue services started on time.

Achieving successful progressive start-ups requires that attention be focused on early integration, particularly for the systems critical to revenue service—ticketing, track, signalling, traction power and trains. The project will always aim for flexibility to allow for multiple options such as technological replacement. Keeping options open requires engineering teams to consistently favour open standards to identify the right solutions, thereby preventing potential constraints due to sole sourcing.

De-Risk Project Design and Delivery

Optimizing and phasing toward revenue service

The successful SI strategy applies iterative analysis to establish an efficient and adaptable plan. During the design phase, the integrator will start from the end goal and reverse-schedule the project to establish the critical path that promotes the rapid start-up of specific systems and subsystems within the constraints of the construction program. At this stage, the engineers will review the design for testability and may require modifications in coordination with the site manager to facilitate the construction, manage tests and increase safety through isolation from potential risks (such as electrical, mechanical) for all people present on site.

To support earliest revenue generation, the systems integrator will focus on the most challenging system first to prevent delays by taking early corrective actions. The virtual twin enables the systems integrator to foresee the ripple effect of each modification in the system of systems during the final phases of integration before passenger service. The virtual twin model identifies impacts of a modification in real-time, providing a consequence tree. Through the consequence tree, the virtual twin model will be used to validate which additional tests are needed on-site to avoid regressions, thereby safeguarding the existing system operations.

Systems simulator equipment is introduced at the factory, once the factory acceptance test is completed, to conduct the Integrated Factory Acceptance Tests (IFAT) to rectify any issues prior to shipping manufactured goods; IFAT tests system of systems (SoS)[4] for interoperability. The next step introduces equipment to the SI lab. Situated at the backup operations control centre (BOCC), the testing in the SI lab increases the reliability and expands the scope of the early IFAT, reducing the quantities of anomalies and potential problems to be corrected on site. This results in cost savings from reducing field repairs and also prevents scheduling delays for rail service operation. The SI lab integrator work process also includes testability evaluation, leading to the incorporation of specific features into the design—to facilitate, accelerate and secure the future tests to be performed on-site (i.e. designed to be tested).

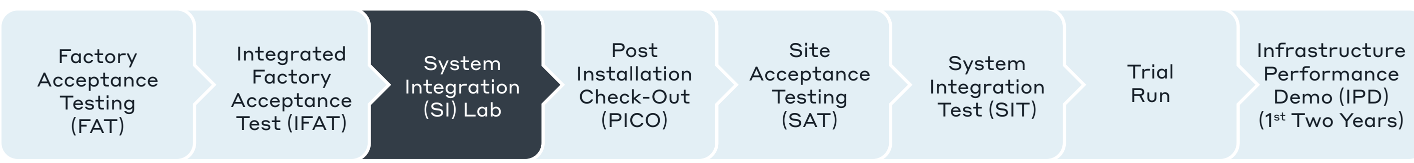


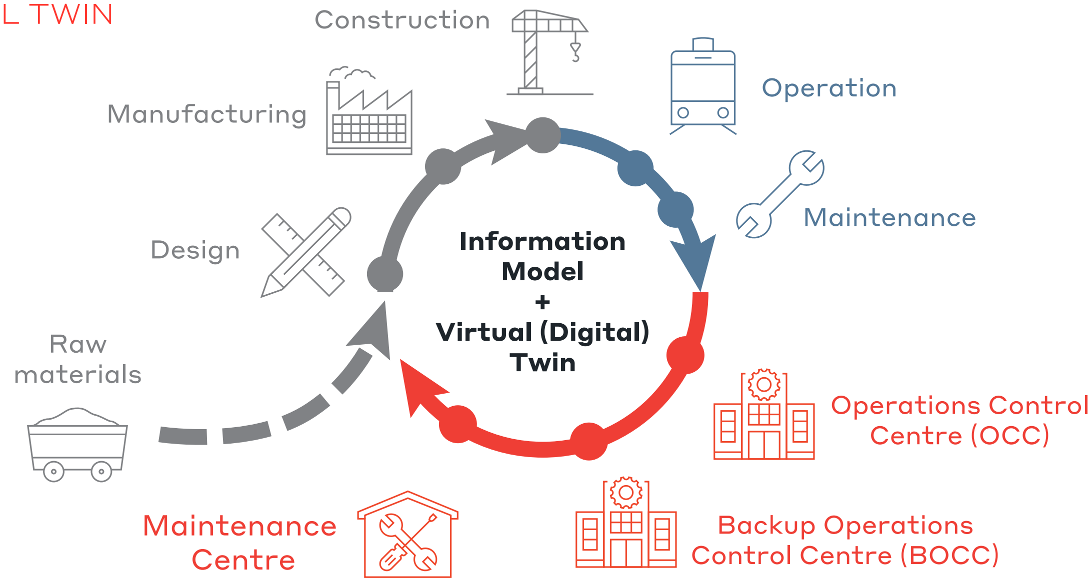
Figure 2 – Systems integration process with the systems integration lab at the core (before field installation) for cost savings and schedule compliance. The SI lab enables the integrated verification of products and configuration before deployment, to prevent regressions and delays.

The virtual model complements the work of the SI lab and the site tests through the consequence trees, permitting the team to identify necessary tests and conduct as many tests as possible in the lab.

The SI lab, situated at the BOCC, contains equipment, samples and/or simulators replicating part of the system, allowing the team to conduct most of the integration and non-regression tests—thus reducing the number of tests to be conducted on-site and resulting in time and cost savings. The SI lab is also used as a configuration management check-point ensuring that the exact configuration installed on-site is always verified and under control throughout the life of the system. This reduces start-up delays and risks.

4 System of systems (SoS) refers to large-scale distributed systems, the components of which are complex systems themselves.
Source: ScienceDirect.

VIRTUAL TWIN



Construction 2-10 years	**Operations** 20-50 years	**Maintenance** 20-50 years+	**Operations Control Centre** 20–50 years+	**Backup Operations Control Centre (BOCC)** 20–50 years+
Integrated information model is updated with as-built data, and a virtual twin is created.	Virtual twin of the built assets is updated throughout the lifecycle of the asset with accurate and actual data.	Virtual twin—with detailed information about asset specifications, maintenance history and operational data—helps determine whether the life of an asset can be extended or whether the asset must be replaced.	Only validated systems and equipment are installed at the OCC and commissioned with the operator.	The SI lab enables the integrated verification of systems, products and components before deployment, to prevent commissioning delays.

Figure 3 – Typical rail project lifecycle with virtual twin and SI lab

The SI lab integrator work process also improves testability evaluation, such as improving the test procedures or adding specific features to the design implementation to facilitate, accelerate and secure the future tests to be performed on-site (i.e. designed to be tested).

Linear infrastructure installation requires teams to move along great distances to detect, test and correct anomalies. Setting a comprehensive configuration management plan in the early project stages to map out and understand the installed configuration for each process step involved will help prevent regression, modifications and retests. Non-regression tests using the virtual twin model and simulation tools in the integration lab will permit the re-validation of new revisions or modifications before their site deployment, thus preventing most regression.

Apply the Virtual Twin at the SI Lab

Why	**How**
• Optimize resource usage	• Helps determine the necessary tests to prevent regressions; helps optimize the tests for the SI lab.
• Reduce field repairs	• Helps to prevent regressions on-site and improve preventive maintenance.
Uphold schedules	Simulate operations, anticipate difficulties and take corrective actions.
• Build owner confidence	• Transparent engineering and reporting builds owner confidence.
• Progressive start-up	• Provides the agility to implement transitional configurations and run partial services with the necessary safety standards.
• Future financing	• Demonstrates future development through simulation; helps to validate anticipated efforts, risk reductions and mitigations.
• Incremental skills development	• Tests team can trial the test sheets and train themselves to execute the tests. The virtual twin helps validate the tests-and-commissioning safety plan.

Adopting a holistic approach from design to warranty—using a one-page view linear schedule and geospatial database—supports early analysis of the construction program and its coordination with the subsequent incremental integration process.

A dedicated scheduling methodology is used to create a one-page view construction program, identifying the common milestones between the linear system construction (track, overhead catenary system, road) and the localized construction (bridges, buildings, traction power sub-systems, operations control centre). Correlation and coordination between the linear schedule and localized graphical schedule (Gantt) schedule will highlight the common milestones.

This technique will facilitate the identification and resolution of inconsistencies, bottlenecks from any part of design or construction (e.g. utilities modification, resource and equipment availability, cadencies). Identifying those major roadblocks is very difficult without a comprehensive view of the project, which will also prevent sequencing mistakes.

In addition to the SI lab and the one-page schedule view, the third key element to deliver a reliable, operable system is to pre-test assets and their systems in a controlled environment before introducing them to the main line. As an example, it is not possible to start testing a train on the main line as long as the first track section is not connected to the maintenance centers (in situations where the trains are assembled in the maintenance center after transportation). However, a specific test track could be built inside the maintenance center to solve the issue provided that that specific roadblock has been identified in advance.

The integration methodology, strategy and schedule will therefore be very dependent on the construction program summarized in the linear schedule. Every system test phase will be interdependent with the test phases of other systems and construction progress. The construction schedule and integration schedule are the result of an iterative process implemented in parallel with construction testing and commissioning.

At this stage, the SI capability puts focus on the construction milestones leading to integration with host railways and existing systems. Those systems are under operation and must remain available. This will necessitate a modeling effort to anticipate and secure the integration approach of the existing operational installation.

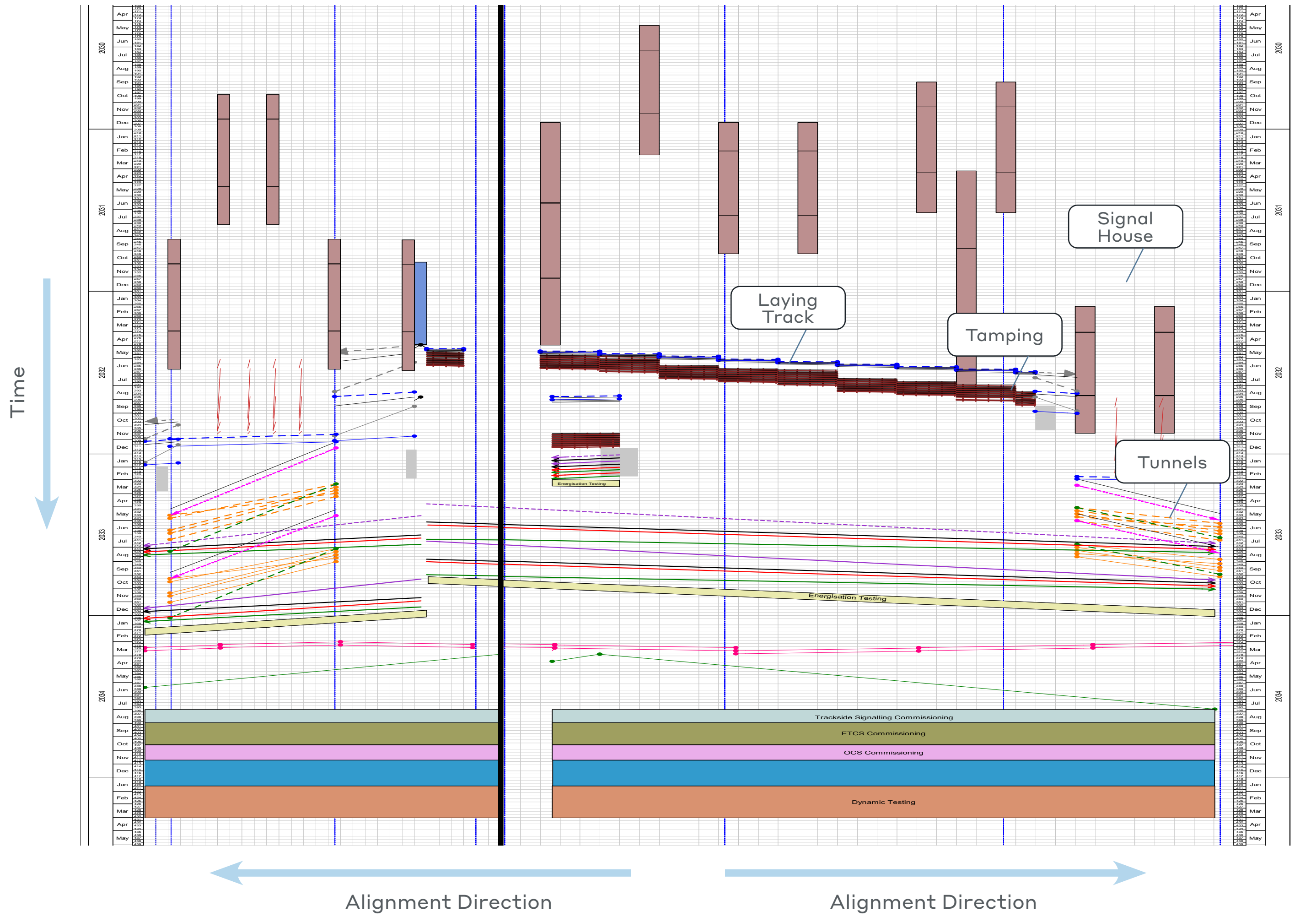


Figure 4 – Time-Location Schedule (TILOS)

To accelerate the performance, complete the integration platform and increase the quality of the SI process, the virtual twin (the 3D model) provides a reliable identification of the areas impacted by a modification to a system and the potential border effects on the other new deliverables or existing systems.

Through a comprehensive system-of-systems mapping—with all the systems, sub-systems and components in the virtual twin—the project developers can quickly and reliably identify areas impacted by changes to one of the systems. Since many requirements change during the typical railway development phase, it is important to update and maintain the models to identify those potential problems in advance and support the proper, safe, reliable and secure integration of all new and existing systems.

The virtual twin, with capabilities for multiple simulations and virtual commissioning, enables designers and construction decision-makers to see and address obstacles before moving to the field for construction. By catching errors in the design phase, retrofit and re-work costs—typically five to ten times higher in the field compared to the factory—can be avoided. This capability reduces the risk of costly re-working and streamlines the commissioning process.

Interoperability

Enable Systems to Connect and Communicate with One Another

Why

- Safe operations
- Reliable passenger services
- Availability of rail cars
- Certified operators
- Optimize operations
- Reduce costs
- Noise abatement
- Accessible services for all ages

How

- Integrated scheduling tools for circulations on multiple host railways
- Systems functional integration – applications for passenger service
- Common safety standards
- Common operating rules

Interoperability requires interoperable technical specifications for:

- Integrated safety management process (Tunnel / Signalling / Traction Power)
- Systems functional integration for passenger service applications
- Integrated scheduling tools to prepare circulations on multiple host railways
- Operation and traffic management / Cross-border dispatching / transfer
- Shared or compatible rules and operating practices
- Set of driver qualifications and training
- Set of rolling stock certifications / Passenger Trains / Freight
- Rolling stock Capacity / availability
- Qualified personnel, resource management
- Infrastructure
- Noise
- Persons with disabilities
- Freight Services specific applications

New railway networks depend on the communication between many existing services and the interactions with existing infrastructure, such as road crossings, signal and train control systems, power systems and stations; they must work together so that the goals of the owner and operator are met, the priority being safe operations for passengers and employees.

The safety management process implemented for all new rail systems should offer a solution to maintain the validation of existing and proven subsystems and components.

The overall new system requires integration with the existing system while still allowing for further modernization to develop future-ready infrastructure. By paying close attention to interoperability needs, existing services can be expanded with new rail lines or new systems. For stable operations, interfaces with the existing rail network must be analyzed closely to confirm that the function and performance of new services meet strict codes, standards and service mandates—for safety, reliability, maintainability and availability.

To deliver a fully functional railway service, the 3D virtual twin provides a digital platform showing a detailed view of each system—for ease of integration with other systems or subsystems and subsequent interoperability. The virtual aggregates the BIM models from each discipline, thereby creating an SoS view, detailing out each system, subsystem, components and interdependencies; this process allows engineering teams to easily identify impacts from modifications or failures within the network, thereby de-risking the commissioning of the new system.

The virtual twin in model format allows design, operations and maintenance teams to collaborate early, anticipate regression and border effects, and initiate specific tests with new systems in order to prevent those regressions (disruptions) on the existing operational railway.

This will help the successful launch of new services by anticipating and prioritizing the most complex system-testing specification and also permits modifications during the design phase by enabling pre-examination of subsystems in a modular system-model approach before implementation and testing phases.

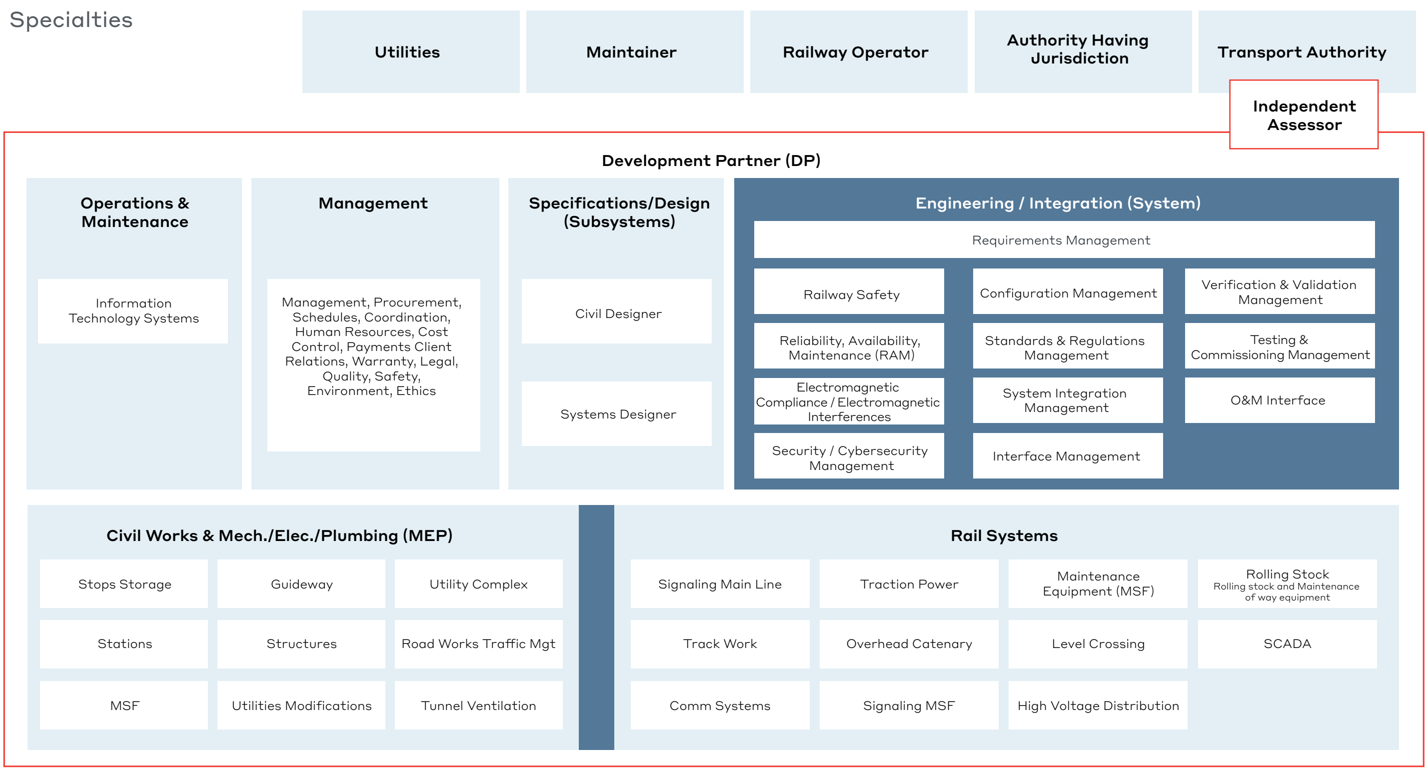
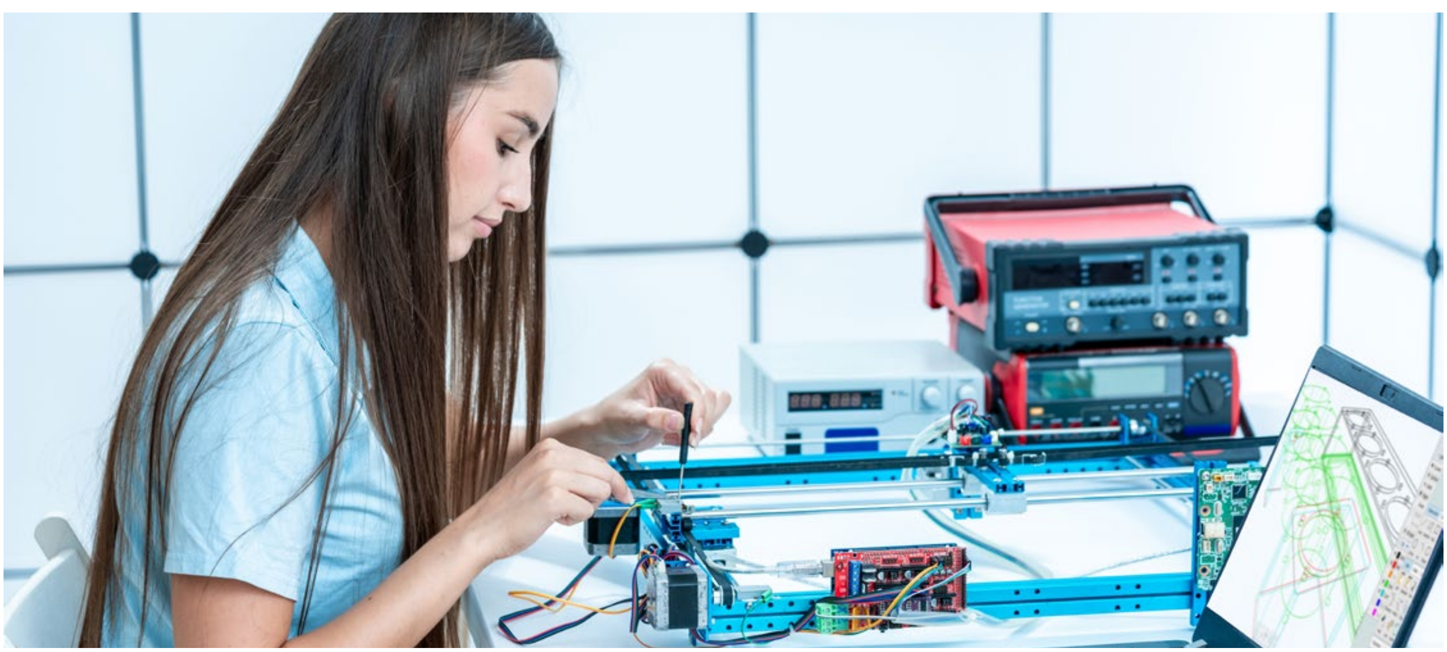


Figure 5 – Work Package Breakdown Structure (WPBS) – Each engineering discipline organizes its work process following the whole project lifecycle.

The virtual twin shows SoS mapping of the interfaces, highlighting those that could lead to potential vulnerabilities and enables the cybersecurity team to scrutinize these interfaces.

Interoperability also requires synchronization with shared railway systems operators (and host owners) for alignment with schedules, safety and capacity.



Key Performance Indicators (KPI) reporting

For an overall transport system to be considered as compliant with performance standards, many stakeholders need to contribute their scope deliverables in a standardized manner, with varied tests and exact measurements. The impact of one scope package that does not perform can impact other parts of the network. Key performance indicators help to standardize the testing for interoperability.

Management Performance KPI	Engineering / Design Performance KPI	Construction Performance KPI	Operation Performance KPI	Maintenance performance KPI
• Quality of performance reporting evaluated by an external auditor • Quality of financial reporting and forecast • Change order / Claim management • Turnover (employee) • Value for money	• Engineering assurance management report • Number of engineering anomalies corrected during design • Number of Design anomalies corrected during construction • Engineering services during construction • Performance results (FRACAS)	• Schedule management • Actual / Forecast • Cost Management – Budget Actual / Forecast (Claims excluded) • Adherence to Design Function & Performance (RAMS) • Reporting Quality	• Safety and security performance measurement • On-time performance • Passenger experience • Customer satisfaction	• Safety and security performance measurement • Adherence to preventive maintenance schedule • Accuracy of FRACAS reporting. • Corrective maintenance efficiency, work orders cycle time • Impact of maintenance issues on operational schedule

Figure 6 – Sample KPIs for SI and interoperability compliance

Modernization

Plan Modernization for Both New Systems and Existing Networks Linked with New Systems

Why

- Improve passenger services
- Introduce new operational capabilities
- Prevent disruption of existing services
- Improve operating efficiencies
- Eliminate low value repetitive tasks
- Reduce costs for modernization

How

- Agnostic: open architecture
- Backup operations control centre (BOCC) simulation
- SI lab for pre-testing

Providing a rail system that can be flexible and provide new capabilities or better services requires the ability to adopt new emerging technologies. This must be done with minimum service disruption and be predictable to minimize impact on customers. To achieve this goal, a detailed integration process must be established for all new infrastructure, systems or components.

Adopt industry standards to enable seamless integration of new functionality

- Adopt commercial off-the-shelf components (COTS). Avoid black box technologies.

- Adopt as many standardized products as possible and open-sourced systems.

- Adopt standardized communications protocols.

- Clearly separate functional systems to facilitate the replacement of any single component.

- Plan for and create an SI platform or SI lab, which also serves as the backup operations control centre. This environment will be used to check the configuration management and operational conformance of all electronic equipment and components, e.g. CCTV cameras before field installation to simulate operating environments (in a test bench environment) for configuration management and component testing prior to installation in the field to save time (i.e. months). The SI lab must be budgeted and constructed early in the project to enable integration platform verification before installation.

The systems model entered into the digital framework defines components by function, performance (RAMS – reliability, availability, maintainability, safety), interface and environmental parameters. As time goes on and technologies and constraints evolve, the engineering team maintains a permanent technological watch to ensure that any trend diverging from the model will be considered in a controlled manner or that a new technology which is compatible with the defined model could be adopted if needed.

Major projects already use systems integration labs. The Thameslink Programme in London has seen several iterations of the SI lab during its lifecycle. These labs de-risked critical elements of the program and allowed it to maintain pace. Not least of these is the ETCS National Integration Facility (ENIF), specializing in European Train Control System (ETCS) development. ENIF has become a world-leading SI facility capable of hosting multiple suppliers and configurations of systems, including on-board, wayside, and central command and control systems. ENIF is now a national resource open to any project with an ETCS integration need. This facility is expected to be pivotal in the future East Coast Mainline and North City Line ETCS programs, the most advanced in the United Kingdom to date. So highly regarded is the value of an SI facility that, in early 2019, Network Rail's Group Digital Railway engaged with the supply chain via the Joint Development Group to specify the next-generation SI lab. WSP was part of that team.

Knowledge Sharing

Create Knowledge Centres for Workforce Development

Why

- Build skills for the industry to replace retiring population.
- Attract new talent with innovative work processes.
- Improve productivity and attractiveness of the workplace through digitalization.
- The virtual model enables training for students by bring the model of an operational system into the classroom.
- Knowledge-sharing, i.e. learning from each other, builds awareness for many people.
- Understand how individual contributions can help build better communities and societies around the world.

How

- Virtual twin for ongoing operations insight.
- Improved maintenance tools for asset intelligence throughout the whole lifecycle.
- Simulation and augmented reality builds an interesting learning environment.

In addition to its pivotal role in developing sophisticated rail systems, digitalization enables the collection of knowledge and knowledge-sharing, essential to the growth of the rail industry. Through collaboration with academic institutions, the rail industry can achieve ongoing knowledge-sharing as well as capacity-building toward establishing a capable workforce—one able to develop and maintain reliable services throughout the lifecycle of increasingly sophisticated rail systems. Skills development is a key area requiring immediate attention. Establishing learning academies is an effective route to support a growing pool of professionals. By enhancing skills development and opening up new long-term career opportunities, learning academies also present a new pathway for Indigenous and non-Indigenous communities to generate economic wellbeing and advance social equity for populations.

Rail projects have a positive cascading effect including economic, social and environmental impacts, to bring new jobs locally and throughout supply chains. For example, major projects often require a workforce in the range of 5,000–10,000 people. They also support inclusion by connecting communities not easily accessed.

Conclusion

As railways become more complex, digitalization becomes central to delivering safe and reliable services. SI plays a central role in this process—to manage parallel workstreams, link new systems together and link new systems to existing systems.

Digitalization can bring the full capabilities of SI to any major rail project, creating a more efficient and effective path to project delivery—with the expected outcomes for rail owners, rail operators and passengers—thus saving money and time.

Introducing digitalization upfront to manage rail systems throughout their lifecycle will enable a comprehensive view of project requirements and progress for all stakeholders while building in adaptability for adjustments—essential to any infrastructure project seeking to support a better quality of life for people through convenient and inclusive access and reliable journeys.

Related Reading: Delivering Intelligent Integrated Digital Rail Systems and Operations & Maintenance

Enterprise Asset Management and Digitalization of Rail Systems

WSP

Jennifer Verellen

Global Rail & Transit Leader
Senior Vice President
Transportation Systems
WSP Canada

Jennifer.Verellen@wsp.com

Lucy Casacia

Vice President
Digital and Smart Solutions
WSP Canada

Lucy.Casacia@wsp.com

Arnaud Ceyzeriat

Technical Director
Digital Delivery, Rail & Transit
WSP Canada

Arnaud.Ceyzeriat@wsp.com

Deutsche Bahn

Fabian Möhring

Executive Vice President
DB International Operations

Fabian.Moehring@db-eco.com

www.db-eco.com

Marc Willich

Chief Digital Officer
DB Engineering & Consulting

Marc.Willich@deutschebahn.com

www.db-eco.com

Dassault Systèmes

Corinne Bulota

Vice President
Infrastructure, Energy
& Materials Industry
Dassault Systèmes

Corinne.Bulota@3ds.com

Stéphane Aubert

Senior Industry Business
Value Consultant
Infrastructure,
Energy & Materials
Dassault Systèmes

Stephane.Aubert@3ds.com

As one of the largest professional services firms in the world, WSP exists to future-proof our cities and our environment. It provides strategic advisory, engineering, and design services to clients seeking sustainable solutions in the transportation, infrastructure, environment, building, energy, water, and mining sectors. Its 67,200 trusted professionals are united by the common purpose of creating positive, long-lasting impacts on the communities it serves through a culture of innovation, integrity, and inclusion.

WSP Global Inc.
1600 Boulevard René-Lévesque West
11th Floor, Montréal, Quebec
Canada H3H 1P9