



INFRASTRUCTURE

MINING & METALS

NUCLEAR, SECURITY & ENVIRONMENTAL

OIL, GAS & CHEMICALS

Advanced Systems Integration in Major Rail Projects

About Bechtel

Bechtel is among the most respected engineering, project management, and construction companies in the world. We stand apart for our ability to get the job done right—no matter how big, how complex, or how remote. Bechtel operates through four global business units that specialize in infrastructure; mining and metals; nuclear, security and environmental; and oil, gas, and chemicals. Since its founding in 1898, Bechtel has worked on more than 25,000 projects in 160 countries on all seven continents. Today, our 58,000 colleagues team with customers, partners, and suppliers on diverse projects in nearly 40 countries.

Advanced Systems Integration in Major Rail Projects

S. Bhamra, G. Georgiou, M. Georganas

Bechtel and Crossrail
United Kingdom

ABSTRACT

The paper discusses the primary drivers for technological change in railways and examines a new means for integrating complex systems in rail projects whilst meeting customer expectations and securing optimum stakeholder engagement throughout the project life-cycle. The added commercial pressures to shrink timescales in order to secure early revenue income are adding to delivery challenges. Building on lessons from global rail projects a dedicated function of a Systems Integration Authority (SIA) is introduced to sustain aligned delivery to customer requirements and oversee the system integration processes. This would support safe, timely, de-risked and cost-effective delivery whilst enhancing quality of output.

ABBREVIATIONS, ACRONYMS, TERMS

AC	Alternating Current
BIM	Building Information Modelling
CCTV	Closed-Circuit Television
EMU	Electric Multiple Unit
ERTMS	European Railway Traffic Management System
HSR	High Speed Rail
HV	High Voltage
ILD	Integrated Logic Diagram
IRSE	Institution of Railway Signal Engineers
kV	Kilo Volt
LV	Low Voltage
SCADA	Supervisory Control and Data Acquisition
SIA	Systems Integration Authority

INTRODUCTION

Technological advancements have shaped the development of mass transportation networks over more than a century. Railways have played an important role in safely and efficiently transporting hundreds of millions of people and freight all over the world since the invention of the first steam operated locomotive in the UK in the early 19th century. New technologies have changed and improved rail journeys steadily over the past two centuries.

The global application of railways and evolution into various forms to suit operational requirements demonstrates their current and future economic benefit. Today's railways serve mainline routes between large metropolitan cities, dedicated urban light transit applications, freight networks as well as dedicated high speed lines which connect major cities across distant areas.

New technologies are being introduced yearly to respond to growing demand for safer, more efficient, operationally flexible and higher performing railways. The added commercial pressures to shrink timescales for designing and implementing new major rail projects in order to secure early revenue income is resulting in a challenging delivery environment. This added complexity requires new management approaches to lead highly competent engineers through well defined and controlled systems integration work processes.

BACKGROUND

Increasing Technological Complexity and Performance Expectations

Railway technology and systems now serve the full spectrum of functionality to allow the operators to meet key performance and business objectives. Figure 1 shows the timeline for rail systems development and recent trends reflecting the faster rate of change and higher levels of systems integration complexity. This figure is adapted from the diagram by Siv Bhamra and Maximilian Fieguth in the paper titled "Technology Trends in High-Speed Rail" published in the Bechtel Technology Journal in June 2011 (1).

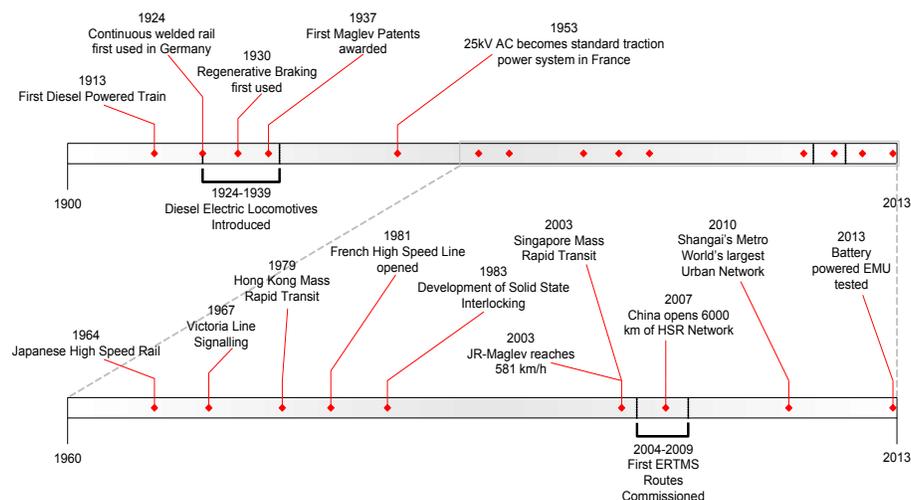


Figure 1. Rail Systems Development Timeline

The primary business drivers for increasing specification and use of new technologies in railways can be summarised in Figure 2 which is adapted from the paper titled "Systems expansion whilst minimising disruption to existing operations" by Siv Bhamra and Marios Georgaras for the AfricaRail Conference, July 2014 (2).

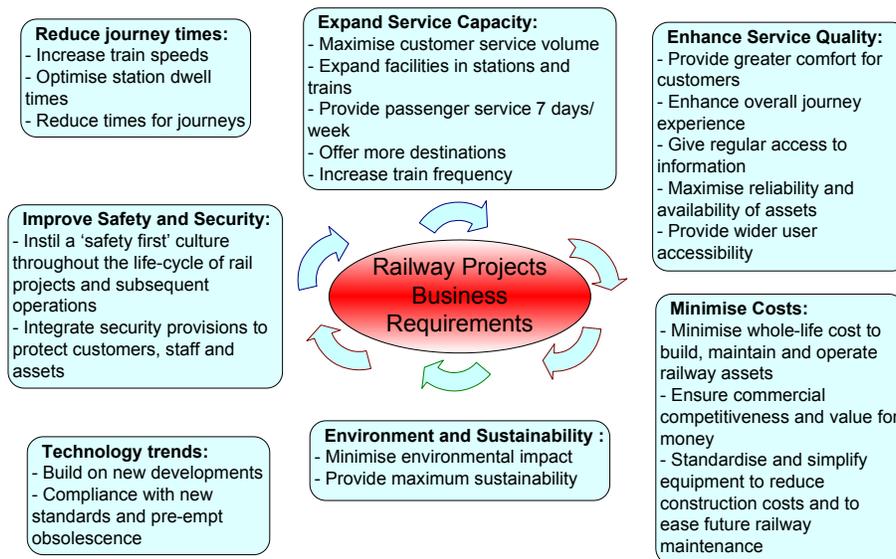


Figure 2. Primary Business Drivers for Major Railway Projects

Rail Technology and Systems Integration

In order to satisfy the business drivers, new rail projects are increasingly being specified in a manner leading to the emergence of highly-integrated railway systems. In particular, over the course of the past 25 years the concept of 'total rail systems integration' has emerged. This thinking leads to the definition in Figure 3.

Systems Integration ensures the rail systems, trains and infrastructure, combined with operations and maintenance inputs, delivers a resilient operational railway meeting customer requirements.

Figure 3. Rail Systems Integration Defined

Modern rail technologies and systems are now becoming highly integrated. In revenue service these integrated systems must work effectively to support safe and efficient operation of trains, stations and other service infrastructure. They also provide timely and accurate information to users, assist operators during any service disruptions as well as provide ancillary services such as operational performance information.

Modern railway control systems are increasingly integrated to provide the following essential operational functions:

- Signalling and train control - ensures safe separation between trains and provides for efficient movement of trains
- Traction power control - monitors and controls traction power and high-voltage inputs to the railway and may even regulate the receptivity for regenerated power

- Passenger information and public address – provides visual and audio information on train arrivals, departures and other details of services on-board
- Telephone and radio communications – allow to transmit the information necessary to control railway operations
- Ventilation and environmental control – provides monitoring and control of ventilation, heating and air conditioning, lighting, drainage and fire fighting systems in railway tunnels, stations, control and equipment rooms
- Closed-circuit television (CCTV) and passenger assistance – provides visual monitoring of railway premises and information to passengers, particularly for assistance and support
- Fire and security – monitors fire and security hazards
- Station management systems – provides station monitoring and control, including lifts, escalators and equipment rooms
- Automatic revenue collection – provides secure revenue collection and associated records
- Remote condition monitoring – provides data on the performance of major infrastructure, including static assets such as bridges and embankments

The above systems can be brought together to form an overall Integrated Control System as shown in the context diagram in Figure 4. This Figure is adapted from Victor Abbott's paper titled "An Insight into Integrated Control Systems for the Modern Railway Environment", which was presented at the Aspect IRSE Conference in London, UK on September 2003 (3).

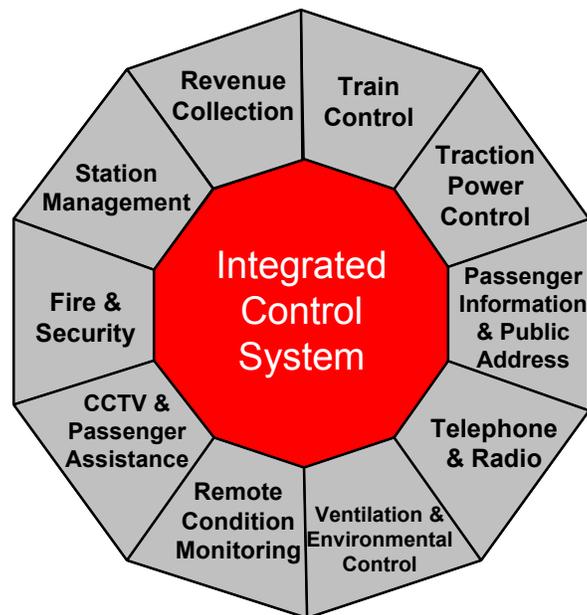


Figure 4. Context of integrated Control System

MANAGING TECHNOLOGICAL COMPLEXITY

Responding to the Complexity Challenge

The increasing technological complexity results in the need for a well controlled working environment where competent engineers can perform their tasks. Given the direct implications for the operational quality and reliability of the final railway, well defined and structured work processes are essential to enable highly complex activities to be performed accurately.

Many of these integrated systems also impact safety-critical functions of the railway, such as signalling and train control, tunnel ventilation and communication systems, particularly in the event of incidents on the operational railway, and therefore require a carefully planned management approach to their implementation.

A dedicated and experienced systems integration function in major rail projects will typically exhibit some of the following attributes:

- Systems culture in the senior leadership of the rail project
- Well understood, documented and embedded processes
- Highly competent integration engineers
- Experienced integration team leadership, supported by all stakeholders
- Early start on rail systems activities (requirements management, concept designs, co-ordination, teaming, interface management, performance specifications, contract packaging strategy etc.)
- Holistic system-to-system structured architecture analysis
- Systems planning: programme Stage Gates and Development Baselines
- Technology integration de-risked through simulations and test facilities
- Technical Key Performance Indicators with both historical and leading indicators
- Careful systems suppliers' scope and interface definitions, selection and invasive management rights
- Concurrent design and validation with the Requirements and Operations concepts
- Progressive assurance and early and regular involvement of the railway Regulators, Operators and future Maintainers
- Effective and consistent communication to everyone involved and impacted
- Lessons learned capture and constructive communication with others in the industry

The above attributes can be characterised in the alignment of experienced and motivated engineers, operators, maintainers and other key stakeholders collectively working towards achieving jointly agreed objectives as well as the integration of complex systems and functionality within a given geographical area. These broader integration themes are shown in Figure 5.

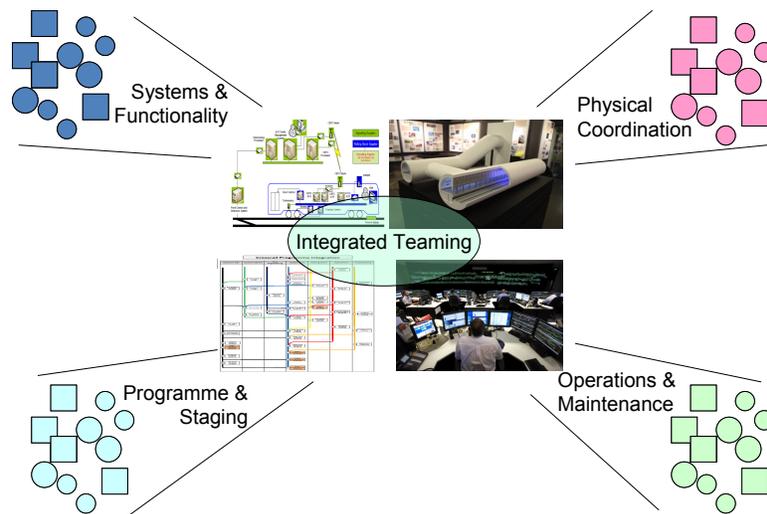


Figure 5. Broader Integration Themes

Balancing System Integration Complexity with Control Effort

The level of management control effort has to be balanced against the understanding of system integration risks to project outcomes. If a project has key systems which are not effectively integrated then there will be implications of cost increases, delayed provision of the railway service to full functionality as well as concerns over future safety, reliability and maintainability. There could also be longer term ramifications of reputation damage and loss of political and other stakeholder confidence.

As the level of systems integration complexity increases, it is necessary to dedicate the appropriate level of highly competent leadership and supporting technical expertise. For comparatively less complicated civil engineering structures and buildings the level of integration complexity and associated risk is relatively contained. However, as advanced technologies are brought together to form highly integrated systems, the need for a dedicated team of personnel becomes essential. Figure 6 shows the relationship between the technological and performance complexity and the corresponding systems integration control effort to manage the risk. Beyond a certain threshold it becomes necessary to appoint a dedicated and highly experienced team to manage the systems integration effort.

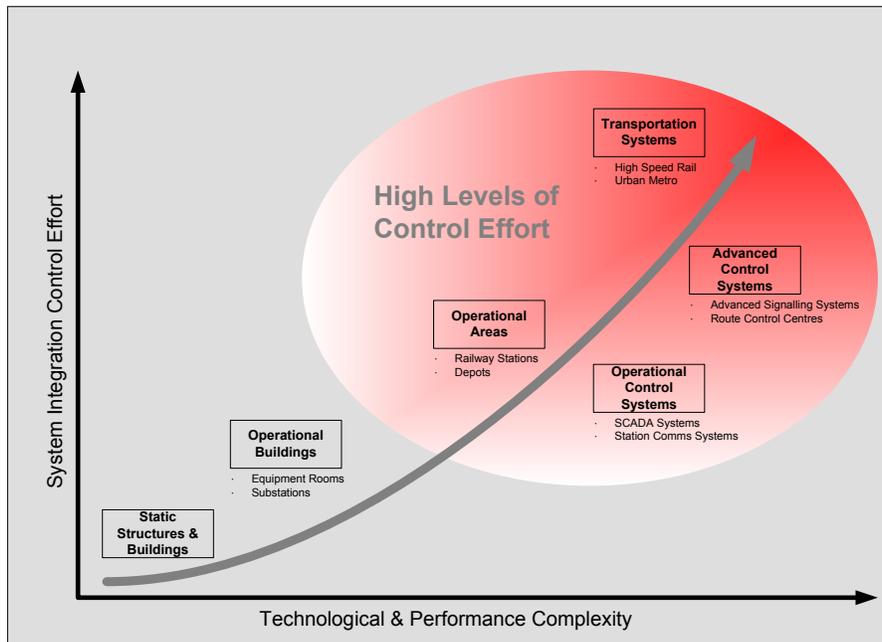


Figure 6. Relationship between Integration Complexity and Control Effort

SYSTEMS INTEGRATION AUTHORITY (SIA)

Overview of SIA

Major rail projects that exhibit significant integration complexity need to establish a dedicated team of engineers, railway operators and maintainers to plan and manage the integration effort through the life-cycle of the project.

One of the key lessons emerging from less successful railway projects has been the failure to appoint a dedicated integration authority from the outset of the project. In complex projects with many disciplines and numerous interfaces and stakeholders it is critical to identify an individual or a team who understands all the technical issues and risks, and who have the necessary experience to take significant decisions to secure successful project outcome.

The concept of an SIA is emerging fresh in the railway industry. It is managed by senior engineers and fully empowered by the Project Director and all relevant Stakeholders. The SIA has the required resources, work processes and management authority to exercise control over the planning, co-ordination, prioritisation and delivery of the works in order to mitigate foreseen systems integration risks, secure successful project completion and deliver an operationally resilient railway into passenger service.

The SIA operates in a BIM (Building Information Modelling) context where all aspects of the railway throughout its life cycle (from materials and procurement to operations and service) are fully integrated into a live online environment. This concept is identified in recent years as "The Digital Railway" and its characteristics are depicted graphically in Figure 7.

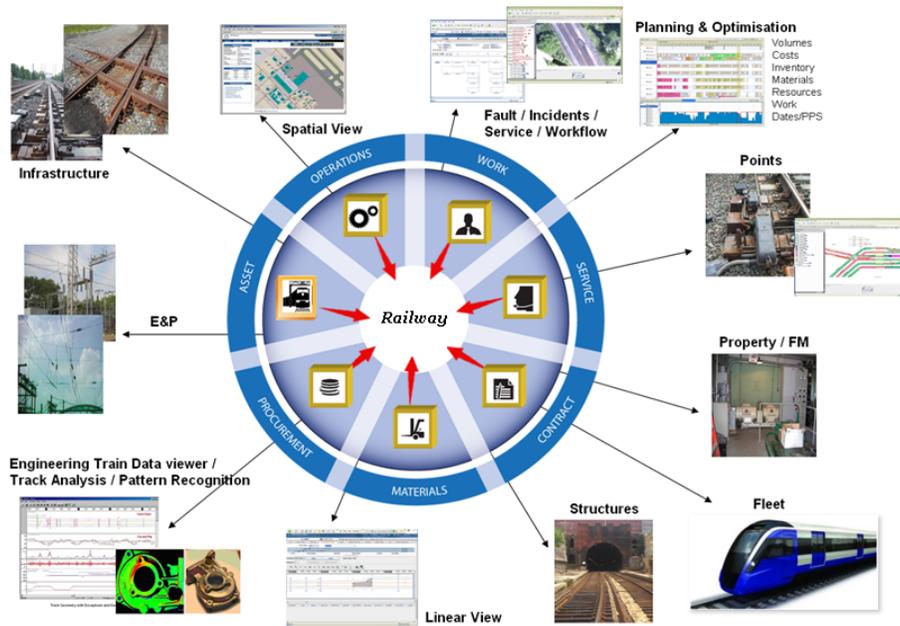


Figure 7. The Digital Railway Concept

The SIA covers all stages of the Systems Engineering life-cycle. These stages are typically comprised as follows:

- Requirements management
- Concept development
- Design
- Manufacture
- Implementation
- Integration
- Testing
- Commissioning
- Operations and Maintenance

Figure 8 shows the strategic role of the SIA in providing dedicated professional integration focus through the 'V' life-cycle stages of complex projects.

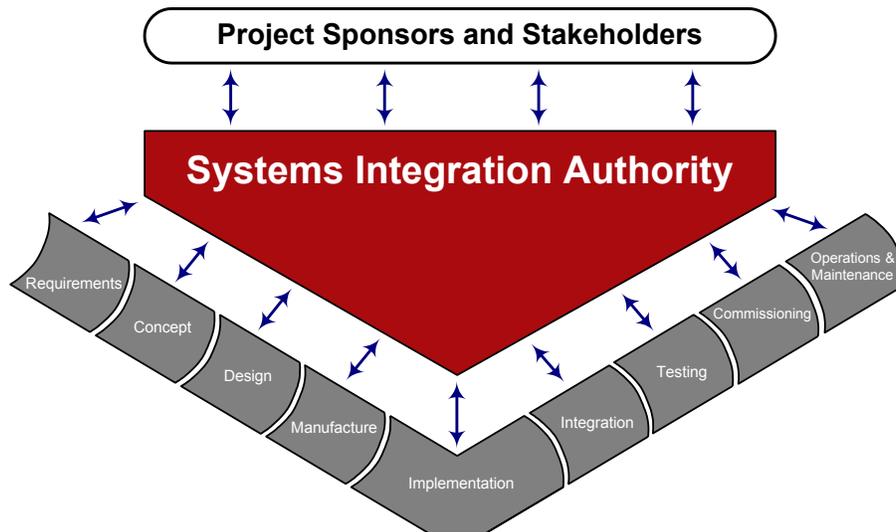


Figure 8. SIA Managing Integration through Project 'V' Life-Cycle Stages

Role of SIA in Project Life-Cycle Stages

Requirements Management

Requirements management is often seen as one of the early phases of a project. Instead, it must be considered as an activity that has a continuing role in the design process, and well into the test, integration, and commissioning phases. The need for requirements management is driven by two major factors; firstly, the increasing complexity of railway projects and equipment evolving technologies, and secondly, the need to address and show compliance to a multitude of stakeholders, customers, users, and regulators. The principal activities in this task can be summarised as:

- Eliciting and capturing requirements
- Analysing and developing requirements, including gap and conflict analysis
- Documenting requirements
- Managing requirements

Conceptual Development Phase

During the concept development phase of the project, the SIA has the opportunity to investigate a number of alternative options. This exercise can be conducted for the project as a whole or for each component, on a system by system basis.

For each project component or system, the proposed options are checked against the defined requirements to gain confidence whether each solution can deliver sufficient performance. This may include sophisticated modelling of service and incident scenarios of each system to confirm that the system capabilities and capacity are adequate.

This activity is followed by assessment of the capital and operating costs of each option. In conjunction with revenue modelling, and depending on client preferences in terms of capital to operating cost, the SIA will guide technical staff to choose the optimum solution for each system and the overall railway.

Design

During the design phase, the SIA's role is crucial in leading technical staff to produce fully coordinated designs. The SIA supervises a rigorous interface management process to ensure that the design of all systems is integrated.

Furthermore, through analysis and synthesis, the SIA allocates requirements to each system and then supports the assurance process to confirm that each system design meets its requirements and this will ensure that the overall railway requirements are met. This verification process is depicted in Figure 9.

Manufacture and Implementation Phase

While the Manufacture and Implementation phase of each system may require less direct supervision, on large projects these phases are unlikely to be aligned without involvement of the SIA. The SIA coordinates the implementation phases of each system to avoid conflicts and to exploit synergies, as well as managing issues and changes identified during these phases.

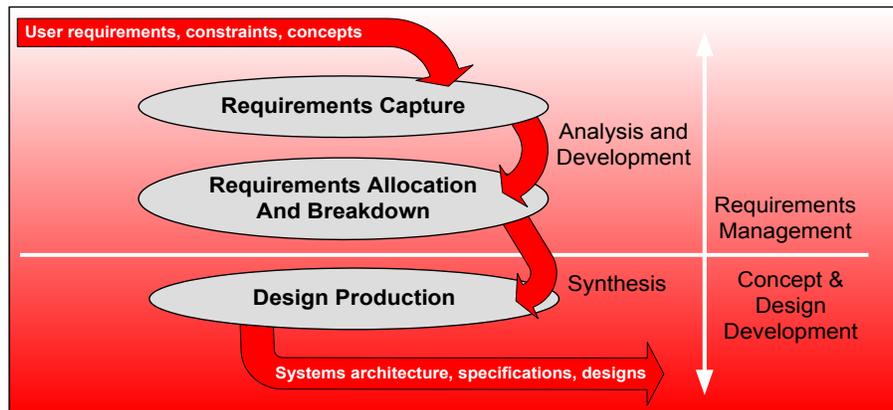


Figure 9. SIA Managing Requirements from Capture to Verification

Integration

The left-hand portion of the "V" diagram, shown in Figure 8, depicts the flow of concepts and requirements being captured, derived, expanded and allocated to design elements in an increasing level of definition and detail, culminating in the implementation and fabrication of all the subsystems and elements. The right-hand side of the "V" diagram describes the test, integration and validation of these subsystems into a working railway.

The mapping across from each side of the V points relates to the fact that a successful testing and commissioning phase is dependant equally on the quality of the design phase as to the processes and their adequate implementation in managing test and integration.

The SIA will rely on the expertise of its systems integration engineers and the empowerment of stakeholders to formulate an effective test, integration, and commissioning Strategy which fully encompasses the railway system and its main interfaces, such as existing infrastructure, existing systems and operational and maintenance procedures and facilities.

This strategy must address the way in which the various elements will be integrated and contains a basic testing and commissioning structure to be used to deliver a railway fit for robust operational performance.

System interface definition may be used to define the boundaries between subdivisions of an elementary system and determine the commissioning lots in order to ensure that testing is exhaustive. It also serves to prepare the Integrated Logic Diagram (ILD), describing the order and sequence of testing subsystems and systems and their tie-ins, logically sequenced to meet the overall programme key dates.

To overcome some of the difficulties of on-site integration and mitigate the associated risk, the strategy should maximise factory and off-site integration testing to prove functionality and interfaces before equipment is delivered to site. A graphical representation of this principle is shown in Figure 10.

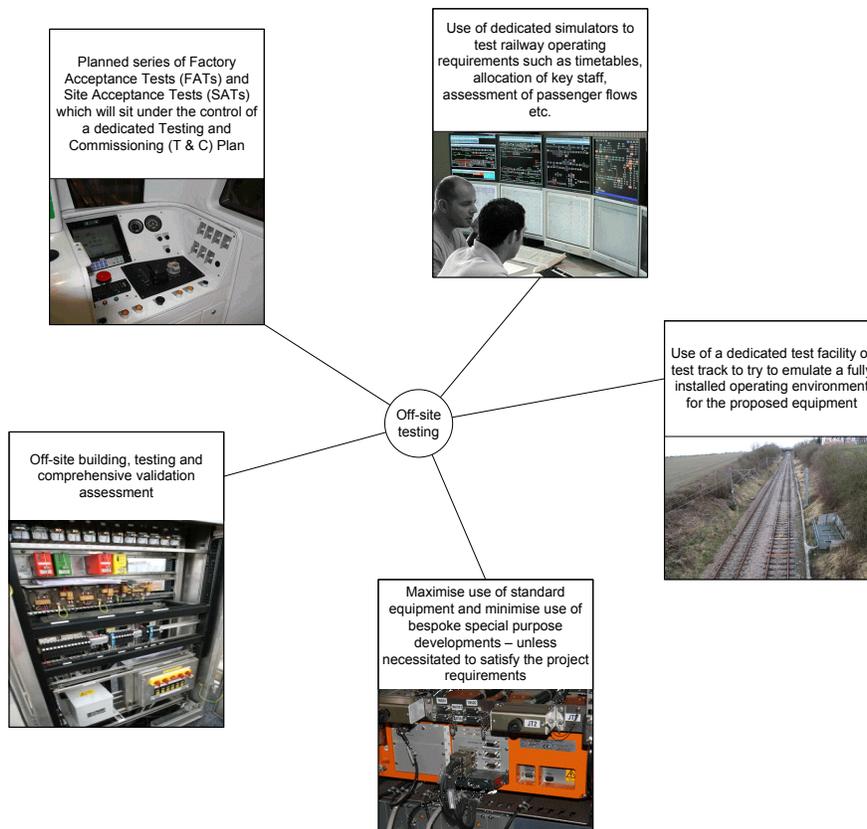


Figure 10. Off-site Testing Options

Equipment should be delivered to site tested and configured. Thus extensive use must be made of simulators and other test facilities including utilising a temporary control module. The balance of options available between actual and modelled/simulated proving is shown in Figure 11.

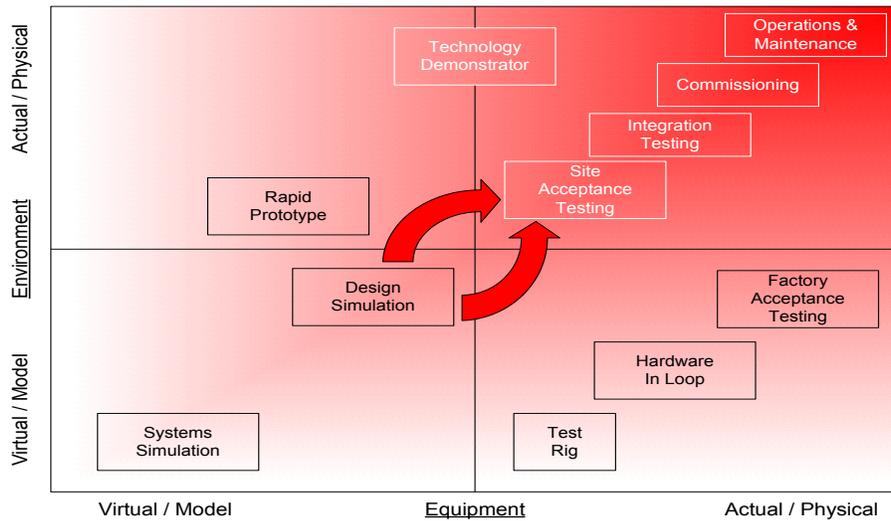


Figure 11. System Development and Proving

One of the tools SIA can use to manage the integration process is a failure reporting, analysis and corrective action system, often implemented using a database, accessible from remote sites, providing a facility for reporting and classifying failures during the integration phase, and for planning corrective actions in response to those failures. It can also be used to provide metrics and performance indicators.

Testing

The purpose of Testing is to expose subsystems and integrated systems to a range of investigations and trials to reveal their performance under controlled conditions against expected behaviour.

Testing is closely aligned to the integration effort, and follows a structure to demonstrate progressive compliance leading to commissioning. The phases typically comprise:

Factory Acceptance Tests validate each sub-system once completed by the manufacturer against requirements, design intent, and standards. Typically the sub-system under test is within an environment of simulated interfaces, drivers, and recording devices.

Static Tests are undertaken when all sub-systems are installed and connected in order to verify they work in accordance with the design and function as demonstrated previously in the factory, and on an integrated basis. Interfaces between the different systems involved are tested by simulation because external systems are not typically connected at this stage.

Static Integration Tests are undertaken when the interfaces between all systems, including the interfaces with the systems of third-parties such as the external railway networks are fully connected. The integration testing regime will follow a defined process that would allow for the progressive proving of technological or performance functionality over an increasing level of geographical area. Defined railway baselines will act as control points to confirm the planned integration

functionality at each test stage has been reached. This concept of progressive integration proving is shown in Figure 12.

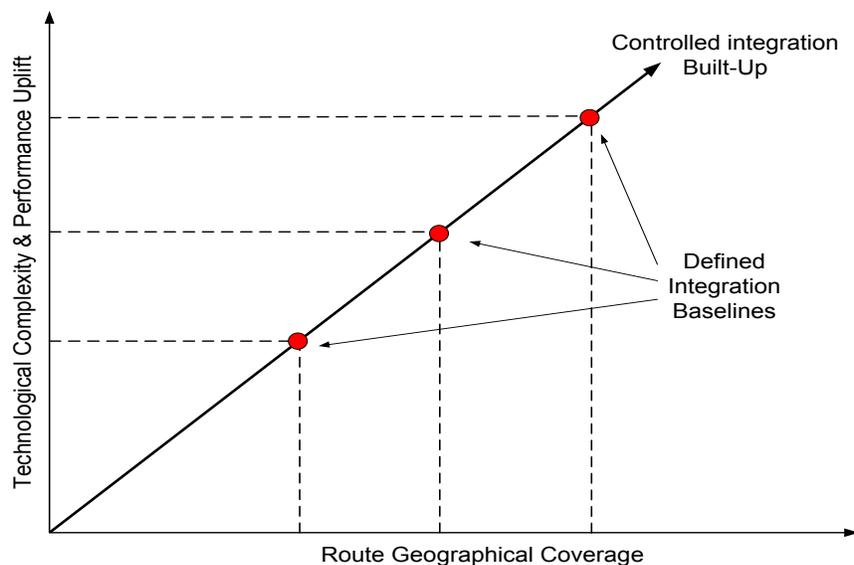


Figure 12. Progressive Integration Proving

In *Dynamic Integration Tests*, the SIA typically approves test train running under controlled conditions. The purpose is to verify that the design and installation of the railway systems comply with their requirements, and that all systems interfaces function and are integrated so that the overall system operates properly and safely to the appropriate standard and in accordance with the requirements.

Trial Runs will involve appropriate integrated testing with trains to demonstrate that the operating railway system is capable of reliably meeting the capacity and other requirements of the programme. Tests will include trials to demonstrate minimum headways, journey times and capacity, plus the ability of the system to operate in degraded modes. During this phase, the railway will be operated under defined rules approved by the SIA.

Trial Operations cater for full running of the railway in shadow passenger operations. This phase enables the operators and maintainers to conduct final preparations before opening the railway to revenue service. This phase also gives opportunity to operators and emergency services to test their responses to scenarios resulting in major service disruption or incidents. The output of these scenarios can be used to update the operations and maintenance response procedures.

Commissioning

Through strategic planning and subsequent supervision, the SIA has the opportunity at the commissioning stage to significantly de-risk the project, notably through phased opening of the railway and sequenced interface commissioning with existing operational assets and systems.

Operations and Maintenance

Once parts of the railway have been commissioned, the SIA's key focus is to secure seamless handover to operators and maintainers. The SIA ensures that training is provided for staff at all levels, handover of assets and records takes place and that ongoing support is provided before project staff are demobilised.

The handover to operations and maintenance is a key milestone and major outcome of the project. However, the role of the SIA continues beyond this phase to ensure lessons learned are captured and conveyed to the next project. The SIA team will commence a new project lifecycle with the benefit of many lessons learned – both formally recorded on systems such as corporate lessons learned databases and intrinsically contained within the experience of project staff themselves.

Life-Cycle progress and performance measuring

Measures and indicators give insight to the management of integration and typically address lagging measures against plans, and leading indicators as a forecast of trouble ahead.

The SIA ensures that the key project milestones are based on the project life-cycle and key integration stages, and will seek documentary and test evidence to demonstrate agreed achievement of claimed progress. The schedule activities will have clear ownership along with assigned leads to manage work at interfaces. Key integration milestones will be agreed and closely tracked by the SIA.

Examples of more detailed systems indicators include progress of requirements verification and validation, issues closed, risks mitigated, interfaces identified and agreed, and problem reports closed during the test and integration phases.

The SIA acts upon these measures and results and implements change to correct issues and set the project back on course. The SIA also anticipates the required focus by the project teams when indicators are put in place and ensures the recovery change effort is what is expected.

Application of cross-functional work processes

The SIA operates in a multi-disciplinary environment. It establishes well defined work processes which are managed and monitored with accountability and ownership. It receives input from practically all the project departments and areas and drives decision making to mitigate risks, reduce costs and provide assurance that the project will perform according to the set requirements. This concept is shown in Figure 13.

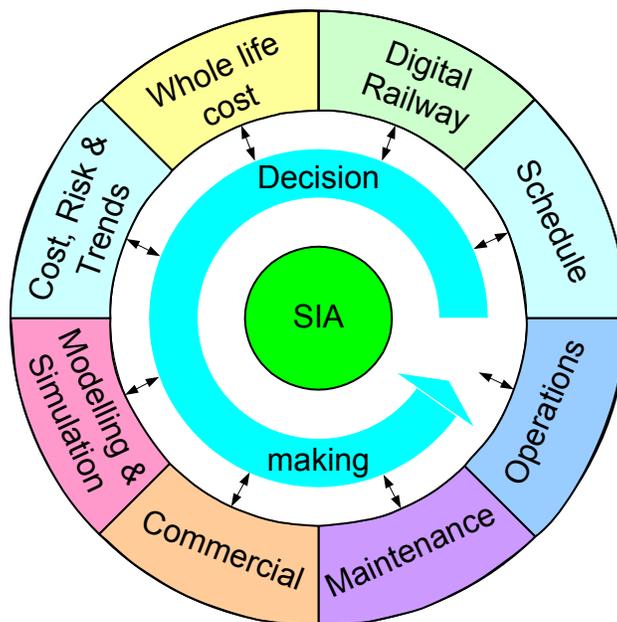


Figure 13. SIA Inclusive Decision Making Process

Competence, Collaboration and Procedures

The SIA will establish the required competence of personnel for the key tasks and the project life-cycle. It is important to appoint staff with well demonstrated previous relevant experience to perform the work and the motivation to engage in a collaborative manner. The mix of the right skills sets required and the teaming between the project disciplines as well as the contractors and stakeholders is essential in order to establish a culture based on trust, mutual dependency and agreed protocols for reaching consensus on highly complex integration issues.

The SIA will also support in defining, developing and harmonizing project standards and procedures. It will work to processes themselves that are aligned and integrated into a suite of standards, procedures, instructions and method statements. Such activity is critical to establish high quality and safe methods of work.

ACKNOWLEDGMENTS

The concept of a dedicated Systems Integration Authority (SIA), as presented in this paper, builds on early implementation ideas that have been deployed on two major rail projects in the United Kingdom. Thameslink established an SIA in 2009 and Crossrail instated a Railway Integration Authority (RIA) in 2010. Important lessons have been captured and various concepts and processes have been applied.

CONCLUSIONS

Advanced technologies are being increasingly used in railway projects to deliver on growing business and operational requirements. Such trends are likely to continue

in the future. Systems integration complexity also continues to grow as new and advanced technologies emerge into the railway environment at an ever more increasing pace.

In major railway projects where there is considerable level of systems integration complexity, a dedicated SIA needs to be actively considered from the early stages of the project. The SIA will consolidate the business needs and the integration requirements and ensure that the risk to successful project completion and delivery of a robust operational railway is carefully mitigated through each stage of the project life-cycle. Figure 14 summarises the overall systems integration role of the SIA in delivering the final railway into passenger operations.

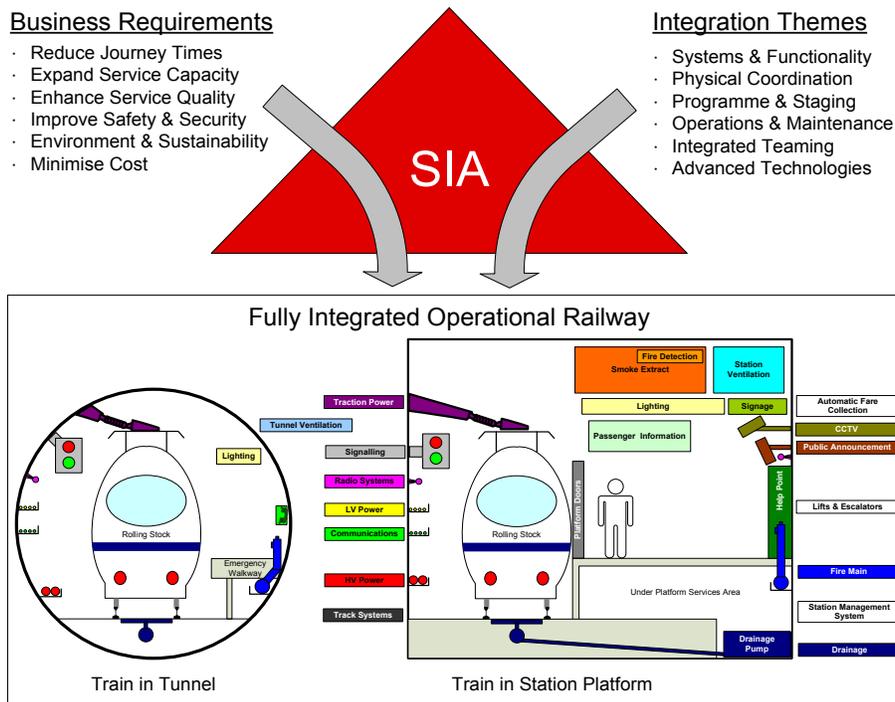


Figure 14. SIA Integrating Requirements to Deliver Operational Railway

The SIA should be established using a highly competent team of experienced engineers, railway operators and maintainers. It will guide and direct the systems integration activity, provide system management including supervision and co-ordination of delivery, clear definition and control work at interfaces and provide input to longer term risk mitigation and change management. The SIA will also help secure project assurance evidence and ensure regular and timely engagement with project stakeholders.

In the absence of an established SIA in major and complex rail projects there is risk of sub-optimal assets being delivered that would not integrate and perform effectively leading to potentially degradation of operational performance, increased maintenance costs and inability to secure intended business results.

The focus of this paper has been on technology and systems integration in the railway industry using the Systems Engineering life-cycle stages under the management discipline of a dedicated SIA. Such processes are equally applicable for use in other industries that have a high level of technological and systems integration complexity. These approaches can go a long way to helping provide certainty of outcome in technically challenging environments.

REFERENCE LIST

- (1) S Bhamra and M Fieguth, "Technology Trends in High-Speed Rail", Bechtel Technology Journal, June 2011
- (2) S Bhamra and M Georgaras, "Systems expansion whilst minimising disruption to existing operations", AfricaRail Conference, South Africa, July 2014
- (3) V Abbott, "An Insight into Integrated Control Systems for the Modern Railway Environment", Aspect IRSE Conference, London, UK, September 2003

