Systems integration – the key to successful implementation of advanced technology train control systems

A. F. Rumsey
Parsons, New York, U.S.A.

Abstract

Advanced technology train control systems represent a cost-effective means of improving the level of service offered to transit passengers in terms of safety, dependability and comfort while providing increased capacity and reduced travel times on an existing transportation infrastructure.

A number of rail transit agencies around the world have implemented, or are in the process of implementing, such systems and while a number of these projects have been very successful, others have been less than successful with significant schedule and budget overruns.

This paper explores some lessons learned from these projects and provides an insight into why some advanced technology projects succeed while others fail. Experience suggests, for example, that the specific technology itself is rarely the significant factor in determining project success. More important factors are the methods used to specify, procure, design, project manage, accept and plan for the operation and maintenance of the new systems, and other institution issues associated with the transition to new technology. This paper therefore also describes and discusses the importance to project success of systems integration techniques to manage the institutional, operational, technical, physical, schedule and contractual interfaces.

1 Background

Advanced technology train control systems represent a cost-effective means of improving the level of service offered to transit passengers in terms of safety,
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dependability and comfort while providing increased capacity and reduced travel
times on an existing transportation infrastructure.

Advanced technology train control systems have the ability to: gather
information on the status of the transit network (in terms of train locations, status
of interlockings, and service performance); communicate this information
between trainborne and wayside processors (using, for example, bi-directional
RF data communications and fibre optic networks); and process and take action
on this information to ensure safe train operations and optimising train
movements to achieve the desired service requirements.

With such systems, train location is typically known with a much higher
resolution than with more conventional train control systems. This allows trains
to operate safely at much shorter headways and permits system operations to
recover more rapidly in the event of a disturbance; all of which provides more
regular and improved passenger service. Shorter headway translates directly to
increased line capacity and measurable increases in ridership, without the major
investment associated with the construction of new transit lines.

Advanced technology train control systems not only provide shorter
headways and reduced travel times but also lower maintenance costs (resulting
from less trackside equipment and improved diagnostics), greater operational
flexibility, enhanced safety (due to continuous automatic train protection),
smoother and more predictable operation, and improved reliability and
availability (through redundant/fault tolerant designs). They also provide a
foundation for further integration of transit system control functions. For
example, the wayside-to-train data communications link can also be used to
support other non-train control functions, such as triggering passenger
information displays and automatic announcements on board trains, and
downloading train health monitoring information to wayside maintenance
centres.

A number of transit agencies around the world have implemented, or are in
the process of implementing, advanced technology train control systems. The
increased dependency on communications-based, computer-based, and software-
Based technologies associated with these systems introduces new project risks,
however, and it is clear that realising the benefits of advanced technology does
not come without significant challenges. As such, while a number of projects
have been very successful, others have been less than successful, with significant
schedule and budget overruns.

This paper identifies some of the critical factors and the institutional,
operational, functional, physical, schedule and contractual interfaces that
determine the success of an advanced technology train control project, and
highlights the importance of systems integration techniques and innovative
design, procurement and construction management practices to increase the
probability of project success.
2 Defining the requirements

As with any advanced technology system, the most critical element in assuring project success is establishing a complete definition of the performance and functional requirements for any new train control system. While the need for a clear definition of system requirements may be self evident, experience would indicate that capturing these requirements in a consistent and unambiguous form is often the most difficult aspect of any project.

2.1 Establish the "vision"

When implementing an advanced technology train control system it is critically important to first capture the "vision" for the new system in terms of operating needs, and benefits to be realised. This could be capacity improvements through sustained short headway operations, achieving a state-of-good-repair, providing safety enhancements, improving system availability, increasing operational flexibility, providing a higher degree of automation, reducing life-cycle costs, etc. If multiple projects are to be used to implement an advanced technology train control system over a complex transportation network, then the agency’s goals and expectations with respect to interoperability and multiple sources of supply should also be clarified. This “vision” for the new train control system can then be used to consistently drive the more detailed system requirements.

To this end, it is considered essential to establish, early in the project, an interdisciplinary task force made up of all of the users and other stakeholders who can affect, or will be affected by, the new train control system. This would include any regulatory authority that ultimately will have a responsibility for approving the introduction of the new train control system into passenger-carrying service. This task force should have the mandate to develop and agree on key operating requirements (as well as the anticipated system configuration to meet these requirements), and to capture these agreements in a “concept of operations” or “design brief” document.

In developing such a top-level document it is important to balance the needs and expectations of the users with the capabilities and limitations of the available computer-based and communications-based train control technologies. As these capabilities and limitations may not always be fully understood, the early involvement of the potential train control system suppliers is also considered essential, in order to ensure that the anticipated system configuration is “buildable” within the desired implementation schedule and budget.

2.2 Develop the technical specifications

Once the top-level “vision” for the advanced technology train control system has been established, the detailed technical specification can then be developed as the basis for the system procurement. The technical specification should specify the operational needs, performance requirements and implementation strategy,
focusing on “what” functions the new system is required to perform, rather than on “how” these functions are to be implemented. The technical specification should avoid imposing explicit design solutions as experience has shown that the suppliers of advanced technology train control systems are well qualified to develop an appropriate system design, once the transit agency has clearly established the functional requirements to meet its operational and strategic goals.

In defining the functional requirements, it is not unusual for a technical specification to focus predominantly on the generic requirements for the system, and in particular the requirements during normal operations. Experience has shown however, that in implementing an advanced technology train control system, satisfying the general functional requirements of the specification under normal operating conditions can be relatively straightforward, and the more significant challenge is complying with any application-specific requirements, specifically the handling of the various failure modes. Complying with application-specific failure response requirements can significantly impact the complexity of the train control system design and these requirements in particular can benefit from careful cost/benefit analyses.

During the development of the technical specification it is therefore critical to establish a failure management plan to identify the required degraded modes of operation and associated recovery capabilities of the new train control system. Such a failure management plan should address, for example, those train control system failures affecting all trains operating within a particular area of control (e.g., wayside equipment or wayside-to-train data communications failures), as well as those failures affecting a particular train operating within any area of control (e.g., trainborne equipment failures).

Such a failure management plan should also specifically establish the extent to which the transit agency will be prepared to accept adherence to operating procedures for the safety of train movements during equipment failure conditions, and to what extent the train control systems is required to continue to provide a level of train protection under the various degraded modes of operation. Establishing an appropriate trade-off between design provisions and operating procedures is therefore a key technical and institutional challenge during the development of the technical specification.

Also, advanced technology train control systems are rarely “stand alone” systems and are typically required to interface with conventional signalling equipment and other train management and customer information systems. These interfaces can be complex, and particular attention needs to given to appropriately defining such interfaces in the technical specification. “Open” system architectures based on accepted industry standards are to be preferred whenever possible.

Similarly, the technical specification needs to clearly and completely define all of the physical constraints imposed by the train and infrastructure
characteristics that can impact the design and installation of the advanced technology train control system.

### 2.3 Industry reviews

Industry reviews at key points during the development of the technical specification can provide beneficial feedback regarding the identification of potential areas of project risk. For example, potential system suppliers can provide early feedback in terms of the feasibility of the specified performance and functional requirements, and can offer suggestions as to how improvements could be made in the specification wording to avoid ambiguity and to minimise project risks. Visits to other transit properties using similar systems and technology are also valuable to experience first hand the features of the new technology and to obtain feedback on lessons learned as well as operational and maintenance experience with the technology.

### 3 Selecting the right system

In selecting an advanced technology train control system for a specific application, while the cost of the proposed system (both initial cost and life cycle cost) is certainly an important evaluation factor, other important factors that need to be considered include:

a) The maturity of the proposed train control system with respect to the requirements of the technical specification.
b) The capabilities of the system supplier to implement the proposed train control system on schedule and within budget.

#### 3.1 Product maturity

The primary characteristics of advanced technology train control systems include:

a) The ability to determine train location, to a high degree of precision, independent of track circuits.
b) The availability of a geographically continuous train-to-wayside and wayside-to-train data communications network to permit the transfer of significantly more control and status information than is possible with conventional track circuit-based train control systems.
c) Wayside and trainborne vital processors to process the train status and control data and provide continuous automatic train protection (ATP). Automatic train operation (ATO) and automatic train supervision (ATS) functions must also be supported, to the extent specified.
There are technical risks in all of these key areas that need to be assessed, as summarized in the following sections.

3.1.1 Train location determination

The foundation of any advanced technology train control system is the ability to safely and reliably determine the location and speed of each train. The design of any train positioning subsystem therefore involves a complex trade-off between safety, availability and system performance. Managing this trade-off represents a generic and application-specific technical risk since the design of the positioning subsystem needs to take account of the specific train and infrastructure characteristics.

A typical train positioning subsystem includes the detection of wayside transponders, or equivalent, to provide an absolute position reference, together with the use of trainborne peripherals (such as tachometers, Doppler radar, accelerometers, etc.) to determine a precise train location between transponders.

Technical risk areas that therefore need to be addressed in considering a specific train positioning subsystem include:

a) Has the proposed train positioning subsystem been successfully implemented elsewhere (i.e. have the generic design/integration risks already been addressed); if so, what were the performance requirements of that system, as compared to the requirements of the new application? Will the performance requirements of the new application require significant modifications to the previously proven subsystem?

b) What technique is proposed to achieve the required level of subsystem safety? Has this technique been successfully used elsewhere?

c) What technique is proposed to achieve the required level of subsystem availability (e.g. redundant peripherals)? Has this technique been successfully used elsewhere?

d) What is the method used to establish an absolute position reference for the train? Is this method sensitive to train and/or infrastructure characteristics? Have the system components been qualified for the particular environment of the new application?

e) What is the method used to establish the precise train location between the absolute position reference points? Is this method sensitive to train and/or infrastructure characteristics? Can the specific components used in the previous application be used unchanged in the new application, or are they required to be re-packaged to accommodate different space/installation constraints?

3.1.2 Data communications link

The availability of a continuous train-to-wayside and wayside-to-train data communication link is also critical to the performance of advanced technology train control systems. Key performance parameters of the datalink (regardless of the specific communication medium) include:
Bandwidth (a definition of how much data needs to be transferred and whether or not this bandwidth is required solely for train control functions, or also for additional non-train control functions).

Message latency (the maximum communication delay that can be tolerated by the train control system in delivering a message in order to meet the overall system performance requirements, in terms of headway and travel times).

Message delivery reliability (the tolerance of the train control system to short term interruptions in data communications).

Technical risk areas that therefore need to be addressed in considering a specific data communication subsystem include:

a) Has the proposed data communication subsystem been successfully implemented elsewhere (i.e. have the generic design/integration risks already been addressed); if so, what were the performance requirements of that system, as compared to the requirements of the new application? For example, will the bandwidth requirements of the new application require any significant modifications to the previously proven subsystem?

b) Are the application “rules” applicable to the specific communication medium sensitive to train and/or infrastructure characteristics and/or the specific EMI environment of the train?

c) What technique is proposed to achieve the required message latency, applicable to short-headway operations? Has this technique been successfully used elsewhere?

d) What technique is proposed to achieve the required level of message delivery reliability - specifically for the case where the proposed communication medium is subject to single point failures? Has this technique been successfully used elsewhere?

3.1.3 Vital processors

Distributed, vital (fail safe) computer systems on the trains and along the wayside represent the final building blocks of any advanced technology train control system. These computer systems are complex devices, difficult to design and validate, because they must not only be designed to exhibit high system availability and have sufficient processing capability to accommodate the specific application functions, but must also be designed such that unsafe failure modes can be assured "never" to occur. Various techniques are used to achieve the required level of safety, including coded mono-processors and multiple processors in a checked redundant architecture. Redundancy techniques, with associated switchover mechanisms are also typically used to achieve the required level of system availability.
Each wayside computer system usually controls a relatively short section of track and as such the handover of a train from one computer system to the next will occur frequently. Computer-to-computer handover must therefore not only be accomplished in a fail-safe manner, but must also be an extremely reliably and dependable function under both normal and abnormal operating conditions.

Technical risk areas that therefore need to be addressed in considering a specific vital processor subsystem include:

a) Has the proposed vital processor subsystem been successfully implemented elsewhere?

b) What technique is proposed to achieve the required level of subsystem safety? Has this technique been successfully used elsewhere?

c) What technique is proposed to achieve the required level of subsystem availability? Has this technique been successfully used elsewhere?

d) What technique is used to “hand off” a train from one wayside processor subsystem to the neighbouring wayside processor subsystem? Has this technique been successfully used elsewhere?

e) Do the functional requirements for the new application differ significantly from previous applications of the proposed vital processor subsystem, requiring substantial new software development?

3.2 Supplier capabilities

In assessing the capabilities of potential suppliers of advanced technology train control systems, a key consideration is the effectiveness of the company’s software engineering practices. The use of formal Software Capability Evaluations of potential suppliers is therefore strongly recommended. These evaluations can be used to gain insight into the supplier’s system development process and can identify software development risk areas. As such, they should be key criteria in the supplier selection process.

The Systems Integration capabilities of the potential system supplier should also be assessed to determine the organization and processes that will be applied to ensure elements of the system function effectively together, to manage internal and external interfaces, and to ensure overall system performance (Reliability, Availability, Maintainability, Safety).

4 Implementing the vision

Having selected the most appropriate system and supplier, experience indicates that in order to successfully implement the new train control system rigorous design management and project management processes need to be instituted by both the supplier and the transit agency. To this end, experience also strongly suggests that an integrated, and co-located, project team is most effective, utilising a true partnering philosophy focused on implementing the project
“vision”. From a design and project management perspective, the following implementation issues are considered particularly critical:

a) Establishing realistic project cost and schedule estimates that draw on “lessons learned” from other similar projects.

b) Adopting a structured system development process that includes a system definition phase early in the project to ensure there is a complete and common understanding between the agency and the supplier on the requirements to be implemented. For example, for conventional train control systems, each transit agency often has its own "typical circuits" for implementing interlocking and signalling functions based on its specific "signalling principles" and operating practices. Advanced technology train control systems offer significant advantages in terms of increased operational flexibility, but in order to realize these benefits in practice, a re-evaluation of the agency’s operating practices and signalling principles is often required. Reaching a common understanding between the agency and the supplier on the required “signalling principles” for an advanced technology train control system is a critical first step in implementing such a system since only when the “signalling principles” have been agreed, can site-specific application designs be developed.

c) Establishing clear requirements for an overall test and commissioning strategy, including use of prototypes, simulation tests and other facilities, to minimise actual field-testing requirements.

d) Reaching early agreement between all stakeholders on the safety certification process. The safety standards and validation requirements for deployment and validation of safety critical train control systems are becoming increasingly rigorous and the safety certification process can represent a significant component of the project schedule and budget. Early agreement on the certification process is therefore critical to ensure that necessary documentation to provide evidence of an acceptable safety assurance process is prepared, submitted and approved at the appropriate milestones in the project implementation.

e) Utilizing well-defined transition plans to develop and implement new operating and maintenance practices and procedures, and to operationally manage the cut-over to the new train control system.

5 The role of systems integration

Throughout this paper, numerous interface issues have been identified that need to be managed to ensure the success of an advanced technology train control project. This includes, for example:

a) Institutional interfaces – to ensure all of the stakeholders who can affect, or will be affected by, the introduction of the new train control system
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(including regulatory agencies) have an opportunity to provide timely input into the system requirements

b) Operational interfaces – to ensure that the design of the new train control system is fully compatible with the operational practices and operational goals of the transit agency.

c) Technical interfaces – to ensure that the design of the new train control system is functional compatible with all interfacing systems and subsystems.

d) Physical interfaces – to ensure that the new train control system can be physically installed and implemented within the constraints of the train and infrastructure characteristics.

e) Schedule interfaces – to ensure that the institutional, operational, functional and physical design interface information for the new train control system is available in a timely fashion, and that the installation, test and commissioning of the system is carried out in a logical and structured manner consistent with the needs of the transit agency.

f) Contractual interfaces – to ensure that the obligations of the system supplier, the transit agency, and other stakeholders, are completely defined in the appropriate scopes-of-work with responsibilities for management of all interfaces and all project risk items clearly identified.

Systems integration, or interface management in its broadest sense, therefore plays a critical role in project success. In the author's view, systems integration is not a stand-alone discipline, but rather an inherent component of design management and project management, requiring an appropriate balance between people and process. People with the necessary expertise and experience to be able to identify and resolve the institutional, operational, technical, physical, schedule and contractual interfaces, supported by proven design and project management tools and processes, such as Requirements Traceability Management tools, Interface Control Documents, Critical Path Schedules, Project Collaboration tools, and Operations/Maintenance Transition Plans, etc.

6 Conclusions

While the benefits of advanced technology train control systems are clear, the implementation experience with such systems is limited. However, by exploiting the "lessons learned" from other projects, and by introducing proven design management, project management and systems integration techniques that are applicable to advanced technology projects, new train control systems can be implemented on schedule and within budget, while meeting or exceeding the expectations of the transit agencies.