

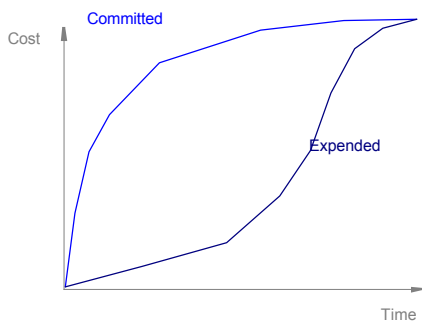
The Value Proposition for Systems Engineering in Railways and Transit

Introduction

The shorter version of this pamphlet puts the main points across in a very few pages for those decision makers in Railways and Transit who require a brief understanding very quickly. This longer version provides additional background useful to engineering practitioners. Text in this version but not the main version is shown against a grey background (as this text).

All too often, complex rail and transit projects suffer overspends and overruns attributable to:

- Requirements which are ambiguous, contradictory, difficult to test or not really required at all
- Mismatches at interfaces
- Technical snags discovered late in the project
- Unexpected difficulties at acceptance



All projects follow the same basic approach. The initial work determines what is needed, and how it will be delivered, with later work delivering the components, integrating and commissioning them.

As the graph shows, while most of the costs are incurred in the second half of the project, they are committed in the first half. Nearly all integration, commissioning and performance problems derive from inappropriate decisions made early in the project.

To deliver the next generation of complex rail and transit projects successfully, we must get a firmer technical grip on them at the outset and maintain that grip until they are complete.

Systems Engineering (SE) is a term used for a body of techniques to:

- understand the requirements that a system must meet and then
- coordinate the different parties to ensure that those requirements are indeed met.

Good SE practice overlaps good project management practice. There is no need to choose between SE and project management: they complement each other. Some SE techniques are already in routine use on railway projects, but others are not. And where those techniques are being used, there tends to be a lack of technical rigor in the way they are applied, as well as little coordination between them.

Systems engineers use 'system' to mean any collection of equipment, people and procedures designed to accomplish a defined function. Conventionally, railway and transit engineers have reserved the term 'system' for the electrical parts of a railway infrastructure (train control, communications, and traction power), but the SE approach expands this narrow use. The SE 'system' still covers the electrical parts of the railway, but adds in the rest of the railway, including the mechanical equipment (rolling stock, points and pumps), the physical facilities (track, structures, stations, yards, and shops), the people who operate and maintain the equipment and paper components such as the set of operational procedures.

Railway and transit organizations can use SE to improve their grip on their projects and so significantly mitigate technical risk. By putting in place a comprehensive, rigorous, and integrated program of SE, they can enjoy benefits that exceed the sum of the benefits resulting from the individual activities.

The table below describes the main activities that would comprise a full SE program in a railway and transit project and describes the principal benefits that accrue from investing in each SE activity. Typically these activities would be shared between the contractual parties involved in a major project.



Activity	Summary Description	Full Description	Summary of value added	Full description of value added
Requirements Engineering	<p>Requirements Engineering is a disciplined approach to</p> <ul style="list-style-type: none"> identifying, assessing, reconciling and defining the requirements placed on a system; following these requirements until they have been met; and tracking changes to them. 	<p>Requirements Engineering is a disciplined approach to working with the customer, suppliers and other stakeholders to identify, assess, and reconcile their needs from a system in the context of what is technically and economically feasible. It starts with understanding of what the stakeholders want to do with the system and then working out what will be needed from the system to support this.</p> <p>Requirements Engineering turns these needs into measurable and verifiable requirements for the system that engineers can use as the basis for design, development and implementation and as a baseline for the management of change throughout the project lifecycle.</p>	<p>Heads off scope creep and prevents both doing too little to meet the requirements and too much. Mitigates the effects of risk and change by ensuring that everyone is working towards achieving the same requirements.</p>	<p>Requirements Engineering helps to guard against scope creep and the failure to provide a technical solution that properly satisfies the customer's needs. It can also support early identification of potential imbalances and over-engineering, where one subsystem is specified to provide a level of performance incompatible with the performance of the system as a whole.</p> <p>When requirements change, good requirements engineering can ensure that the change is applied in a disciplined manner and thereby avert problems caused by having different people working to different requirements at the same time.</p>
Systems Architecture	<p>Systems Architecture is concerned with understanding the subsystems that make up a system, their behavior and the way in which these subsystems interact in order to ensure that they combine to deliver an integrated system which behaves as desired and meets the requirements placed on it.</p>	<p>Development of a Systems Architecture begins with defining how the system to be built or changed is partitioned into subsystems, including the identification of all interfaces between the subsystems. The form and function of each subsystem is then defined, along with the forms and functions of the interfaces. The interface definitions are developed in parallel with the subsystem definitions, so that the overall required functionality of the system is not compromised by interface constraints.</p> <p>It is not necessary to finish Requirements Engineering before starting on a Systems Architecture. On the contrary it is often necessary to create an outline architecture in order to understand what requirements it is possible to meet and to develop the detail of both in unison.</p>	<p>Prevents expensive rework by allowing systematic checking of the integrity and balance of the system and its interfaces while the design is still on paper and rework is relatively inexpensive.</p>	<p>Rapid evolution of railway and transit technologies and the introduction of new technologies from other industries has brought about a requirement for explicit Systems Architecture development. This minimizes the need for expensive rework later in the project lifecycle by allowing systematic checking of the integrity and balance of the system and its interfaces between subsystems while the design is still on paper.</p> <p>A clear Systems Architecture also:</p> <ul style="list-style-type: none"> helps to obtain progressive understanding and thereby approval of the system solution being proposed; distinguishes the characteristics of differing solutions and to facilitate a rational choice between them; and supports Interface Management and Systems Integration (see below).
Verification and Validation	<p>Verification and Validation (V&V) together describe a range of activities to confirm that the system is being built correctly and will meet its requirements and operational needs.</p>	<p>Verification and Validation (V&V) activities include modeling, review, analysis, inspection, integration, testing, commissioning and demonstration, and run throughout the entire life of a project. They start with activities to confirm that the requirements are consistent with real operational needs and finish with activities to confirm that the system as-built meets the requirements and the operational needs.</p> <p>V&V activities detect deficiencies as early in the lifecycle as practical so that they can then be removed with minimum impact to the project time, cost or quality.</p> <p>All projects perform V&V activities at certain stages, even if they do not formally adopt SE practices. SE introduces the concept of V&V as a thread running throughout the whole project and encourages planning this thread of activities as an integrated part in order to remove gaps and overlaps and to arrange activities in order to find deficiencies as early as possible so that they can be corrected at least cost.</p>	<p>Finds flaws early, when they are cheaper to fix, leaves fewer flaws in the final system and streamlines customer acceptances of the system.</p>	<p>Periodic Verification and Validation (V&V) of project development against requirements, design and development baselines is an important contributor to progressive assurance. It offers opportunities to correct anomalies; the earlier the better, since deficiencies are more difficult and therefore take longer and cost more to correct the later into the lifecycle they are discovered (and therefore may not be resolved).</p> <p>V&V also focuses on operational needs and scenarios, concentrating on the intended use of the system and reducing unnecessary functionality and resolving emergent properties. The engagement of key operations and maintenance stakeholders in the V&V activities creates buy-in, which, coupled with periodic informative outreach through system development and delivery, facilitates acceptance of the operational system.</p>
Systems Modeling	<p>Systems Modeling is concerned with forecasting properties of a system as a whole, such as safety, reliability, passenger capacity, and trip times, in order to ensure that the system will meet the requirements placed on it.</p>	<p>Real world systems exhibit emergent properties; that is, performance characteristics of the systems as a whole and not of their individual parts. For railway and transit systems, emergent properties can include safety, reliability, passenger capacity, and journey times. Systems Modeling provides a portfolio of activities intended to forecast emergent properties before a system is built or changed and usually employs a toolbox full of specialized computer software applications, such as computational fluid dynamics, rail network simulation, and traction power load flow analysis.</p> <p>Systems Modeling is also used to verify and validate requirements when the underlying parameters, such as safety, cannot be measured directly.</p>	<p>Avoids painful surprises and allows meaningful, objective evaluation of design alternatives, which can improve decision making and reduce over-engineering. Also helps acceptance by demonstrating the compliance of attributes which are difficult to directly measure.</p>	<p>The emergent properties of railway and transit systems include many of the things that are most important to passengers and operators. Modeling these properties in advance avoids unwelcome, painful surprises and, if applied to the areas of high risk, can return a saving many times the cost expended.</p> <p>Additionally, Systems Modeling allows meaningful, objective evaluation of design alternatives and can improve decision making and reduce over-engineering.</p> <p>Systems Modeling also helps during the acceptance stages by demonstrating compliance with attributes which are difficult to directly measure such as safety, performance, reliability and availability.</p>



Activity	Summary Description	Full Description	Summary of value added	Full description of value added
Interface Management and Systems Integration	Interface Management and Systems Integration facilitates the smooth integration of a system as a whole by identifying and defining interfaces in and around the system.	<p>Interface Management and Systems Integration includes:</p> <ul style="list-style-type: none"> identifying and documenting interfaces: between a system's subsystems (as in Systems Architecture – see above); between the various design and construction contract packages; and external to the system; defining a subsystem integration sequence which progressively replaces simulators with real equipment and allows the interfaces to be checked out in a systematic and orderly manner; and tracking implementation of the interfaces through design, construction, integration, testing, commissioning, and operation to ensure they are verified and validated. 	Awareness and careful management of all interfaces greatly eases system decomposition during the requirements and design stages and the integration after manufacture and construction thereby avoiding costly redesigns during construction or even more costly modifications and retrofits after operations begin when subsystems do not integrate optimally. Allows assurance to be provided progressively and thereby supports system safety certification and acceptance.	<p>A carefully and effectively decomposed and then integrated system meets its targeted life-cycle performance requirements without costly redesigns during construction or even more costly modifications and retrofits after operations begin.</p> <p>Interface Management and Systems Integration:</p> <ul style="list-style-type: none"> ensures that interfaces receive the attention due to them during requirements specification, design and construction; provides a detailed and progressive record of integration activities during construction, testing and commissioning that can support system acceptance safety certification; and defines an integration sequence which can find residual interface problems efficiently so that they can be removed before they become major cost, quality and/or time factors; and supports a clear definition of what suppliers must deliver and when.
Configuration Management	Configuration Management is the process of identifying, assessing, approving and tracking changes to the system being built and all the associated documentation which must be maintained with it.	<p>Configuration Management is about managing technical changes. It includes the activities often referred to as 'Change Management' or 'Change Control' but supports them with a disciplined approach to controlling data so that changes can be more easily assessed and fully and consistently applied.</p> <p>A system's configuration comprises the system being built and all the associated specifications, designs, manuals, procedures and other documentation required to describe it and support its operation.</p> <p>Configuration Management is the process of identifying, assessing, approving and tracking changes to the configuration to support continued compliance with the changing requirements. Configuration Management is achieved through tracking all design and construction changes against an agreed baseline. This allows everyone working on the system at any time in its lifecycle to use correct and accurate information about the system and the engineering process producing it.</p>	<p>Through visibility and control of the system configuration it:</p> <ul style="list-style-type: none"> Improves certainty of quality, time and cost (reduces associated risk); Better informed decisions and clearer lessons learned; Tighter control of changes and understanding of impact; Improves asset management and maintenance. 	<p>Ensuring that all the consequential effects of a change are understood before agreeing to it can improve project quality, save cost, and avoid rework.</p> <p>Ensuring that changes are fully and consistently applied prevents faults and reduces rework.</p> <p>Configuration Management can also provide information about the effects of changes on legacy assets and legacy systems which is useful for operations and maintenance management functions</p> <p>The ability to track and measure the impact of changes helps to learn lessons and improve processes, avoid delay by allowing the consequential effects of a change to be assessed prior to agreeing or implementing the change and then overseeing that agreed changes are fully applied.</p>
Risk Management	Risk Management is a disciplined effort to identify potential events that might adversely impact a project and then take action to head them off.	<p>Risk is potential variation in the outcome of a project. Risk Management is the process of identifying, tracking, controlling and mitigating risk and its impact. All projects perform Risk Management to some degree, even if they do not adopt SE.</p> <p>In the SE world, Risk Management is concerned with technical risks and supports project management by deploying a disciplined effort to identify potential events that might adversely impact a project, determine the potential impact of these undesirable events, and then execute the project in a manner that avoids, mitigates or can recover from the undesirable events with minimum impact to cost, schedule, and performance.</p>	Identification of possible adverse events in advance allows them to be registered and mitigation strategies agreed hence significantly reducing the likelihood of them occurring or reducing the consequences on quality, time and cost if they do.	Risk Management can avert adverse events by raising consciousness of particular risks and causing greater watchfulness or even a redirection of effort. Raised consciousness of particular risks can also reduce the financial and schedule impacts of occurring adverse events by prompting the use of designs, procurement strategies, and construction methods that allow for recovery. Understanding and recognizing risk allows a higher level of confidence that a system will be delivered without delay or overspending.