Engineering a Better Railway for Northern Ireland

Better Process

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Developed by the defence industry and in continuous, evolving use since the Second World War, the systems engineering process has a long-proven track record of reducing risk in contexts where reliability and performance are a matter of life and death. What's more, a study by the National Defense Industrial Association and Institute of Electrical and Electronics Engineers across a wide variety of industries showed a clear and significant relationship between project performance – measured in terms of cost, schedule and satisfaction of technical requirements – and high levels of systems engineering capability.

Systems engineering techniques are fundamentally about finding ways to analyse, model and plan the behaviour of a system as a whole and in its context above and beyond the details of individual components. By having a suite of processes and tools designed to model and anticipate the structure of a system, projects can have assurance from the start that the right thing is being built in the right way, and that the project will interact appropriately with its context. This drives down cost by reducing the risk of mistakes and unanticipated defects, while simultaneously driving up quality by tying engineering activity more closely to precisely defined stakeholder needs.

Over the last 20 years, systems engineering has been seeing greater and greater use in the rail industry, as rail systems become more complex and performance steps up to meeting increasing demand. Network Rail is now working to deploy a Systems Engineering (SE) approach as part of business as usual across the whole of its engineering and asset management activity. Transport for London has embedded SE skills throughout its engineering organisation and employs SE practices routinely on infrastructure projects.

SE has developed a wide range of processes and tools for modelling and simulation, requirements analysis, scheduling, and all parts of the life cycle, tailored to better manage the development of complex systems. Although not designed with any particular industry in mind, it has been in longest use in the aerospace and defence sector, where complex interdependent systems have been the norm for decades. As rail networks become more complex and high-tech themselves, rail industry players have been seeing opportunities in SE techniques to better address the new, more challenging reality of managing a modern rail network.

SE activity has a proven track record of helping deliver complex projects on time, on spec and on budget in the rail industry, maximising the lifetime value of assets to passengers while at the same time reducing cost and risk. Of particular interest is how SE thinking has produced a robust and scientific approach to requirements management and verification, a greater focus on the full life cycle of an asset, and novel modelling techniques for complex emergent behaviour.

The most fundamental insight of systems engineering models is that the structure of a system is what generates its behaviour. As such, the atoms of a systems engineering model are 'system elements': individual components, which are treated as a black box, in an environment from which they take their inputs. These elements are organised into systems, and then even into a 'system-of-systems', which is a model for systems with very independent components and a function that firmly rests on emergent behaviour, like a railway network or a supply chain.

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Using a model like this enables a systems engineer to focus on complex interactions within a system and between the system and its environment, including patterns and trends in how the system changes over time, the impact of time delays in the system's operation, the circular nature of complex cause-and-effect relationships, the problem of where unintended consequences are going to emerge, and the ability of a system to address stakeholder needs.

SE methods are particularly well adapted to circumstances in which requirements change in the course of a development process, as they can much more straightforwardly assess the impact of those changes on the system as a whole. By modelling and planning the asset as a system, it is also possible to anticipate many of these issues and others much earlier in the development process and, critically, prior to generating significant sunk costs.

SE also provides a much more robust process for integration, verification and validation. By using a scientific approach to requirements management with specifically enumerated constraints on what requirements can look like, both individually and as a set, the systems engineering process ensures that verification and validation are conducted in relation to specific, measurable and consistent goals.

Finally, by taking a whole life cycle approach, systems engineering can help to ensure the success of midlife upgrades, prevent the loss of system capabilities during operation and avoid costly compliance failures and other losses during end-of-life disposal.

East London Rail Extension: Systems Engineering in Practice

The 1990s saw two major eastward expansions of the London rail network: the extension of the Jubilee Line to Stratford, and the first stage of the Docklands Light Railway (DLR) extension.

The projects began within a year of one another and were expected to take roughly similar amounts of time. The DLR extension was delivered within the agreed fixed price, and performance requirements were fully met. But the Jubilee Line extension took 21 months longer than planned and cost around two-thirds more than the original budget.

The DLR extension was delivered from the outset using an SE approach, including formalised system requirements, modelling and simulation, and a comprehensive set of integration tests.

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By contrast, the Jubilee Line extension made little effort to maintain a whole system view, and very little provision was made for the huge extent of work necessary on the existing Jubilee line for the project to succeed. The extension was regarded as a bolt-on to the existing railway, and the integration work was not understood until a late stage. Several key decisions were not taken until much later than would be recommended by SE practice, and an SE approach to stakeholder and interface management might have resulted in significant cost and time savings.

Of course, some of the differences between the projects can be attributed to the approach to management and external factors, but the evidence from authoritative accounts of the project suggests that the Jubilee Line extension could have avoided a number of late changes and delivered savings had good SE practice been adopted from the start.

This case study was adapted from those maintained by the INCOSE Transportation Working Group, available free at https://www.incose.org/incose-member-resources/working-groups/Application/transportation.

Maximising Lifetime Value

Because of the long life cycle of rail assets, engineering in rail requires engaging with a more distant past, and a further, more uncertain future, than almost any other industry. Almost any rail project is better thought of as enhancing an existing system rather than creating a new one, and once a system is integrated into the network, it's generally required to last a very long time. Adapting to the interface with legacy systems at the same time as futureproofing the new is always a difficult balancing act, and the rail industry has to think in longer time horizons than most.

Value for money in the rail industry is and must be measured in terms of the full lifetime value of the asset, and systems engineering has tools and processes to better enable projects to address the long term. This goes beyond a planning process that is better able to address the full life cycle: SE activity can also make work more adaptable and make it easier to plan for change.

Stakeholder needs can change at any point in the life cycle, either during development or as part of a midlife upgrade to the system. By developing and maintaining an SE model and SE-grade requirements documentation, engineers have a relatively easy way to adapt to the impact of those changes and determine quickly and cheaply what those changes will mean for the functionality of the system as a whole.

Systems engineering requires the right skills, the right process and the right tools, but applying its techniques to a rail network cuts the cost of quality and reliability over the long term.

This information sheet is an excerpt from SyntheSys Technologies White Paper about Engineering a Better Railway for Northern Ireland. Read the full White Paper [here].

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