MANAGING COMPLEXITY IN RAIL SUPPLY

WHITE PAPER

SyntheSys
TECHNOLOGIES

THE BIG PICTURE

Things are changing fast in the rail supply chain. With £35 billion expected to be spent on new services and equipment in the United Kingdom (UK) alone – a supply chain expansion of 140 percent – the market looks set for a steady period of growth.

This investment comes at a time when the British rail network is being transformed by technologies like cab signalling and condition-based maintenance. The opportunities are there for those ready to step up and take them, but cutting-edge engineering has never been more important.

For rail suppliers, every positive development seems to come with a corresponding risk. There's a huge amount of investment to be won right now, but in rail, every feast costs you a famine. Ill-considered long-term investment in your engineering capabilities can leave you exposed when the good times stop.

Improved technology is driving a lot of current growth, but with this comes pressure to look to the bleeding edge and make difficult decisions about unproven innovations. *Which technologies are going to make the most progress toward decarbonisation? Is the industry going to be ready to embrace the full potential of augmented reality and automation? Will the pace of change in smart cities, the Internet of Things and 5G, be so fast that rail will have to adapt very soon?*

Through all this uncertainty, one thing is clear, rail systems, from the remotest level crossing to the network as a whole, are getting much more complicated. Every little piece of infrastructure, every part of a train, increasingly needs to be looked upon as a detail in a big picture, rather than as something more discrete, with its own discrete maintenance schedule and separately identifiable requirements.

Rail engineering must adapt to this new reality to stay competitive. Walls need to come down and communication needs to step up. The pace of change in technology demands it of us, but it can't happen without the right skills, the right process and the right tools.

Because of the direction the rail industry and technology are going, we believe that the best work will be done where every facet of engineering has the opportunity to see its work in the light of the big picture.

The skills and tools needed to make this a reality are out there, developed by industries which have faced conditions like this before.

Rail engineering could do a lot today, to better manage the complexity it faces now, and in the future.

MANAGING COMPLEXITY

SUPPLY CHAIN MANAGEMENT

It could have a more integrated supply chain, with clearer and more active coordination in the development of complex systems.

RISK MANAGEMENT

It could have a development process which is better able to anticipate project risks, and prevent incurring costs when a failure is spotted too late.

BUSINESS PROCESS IMPROVEMENT

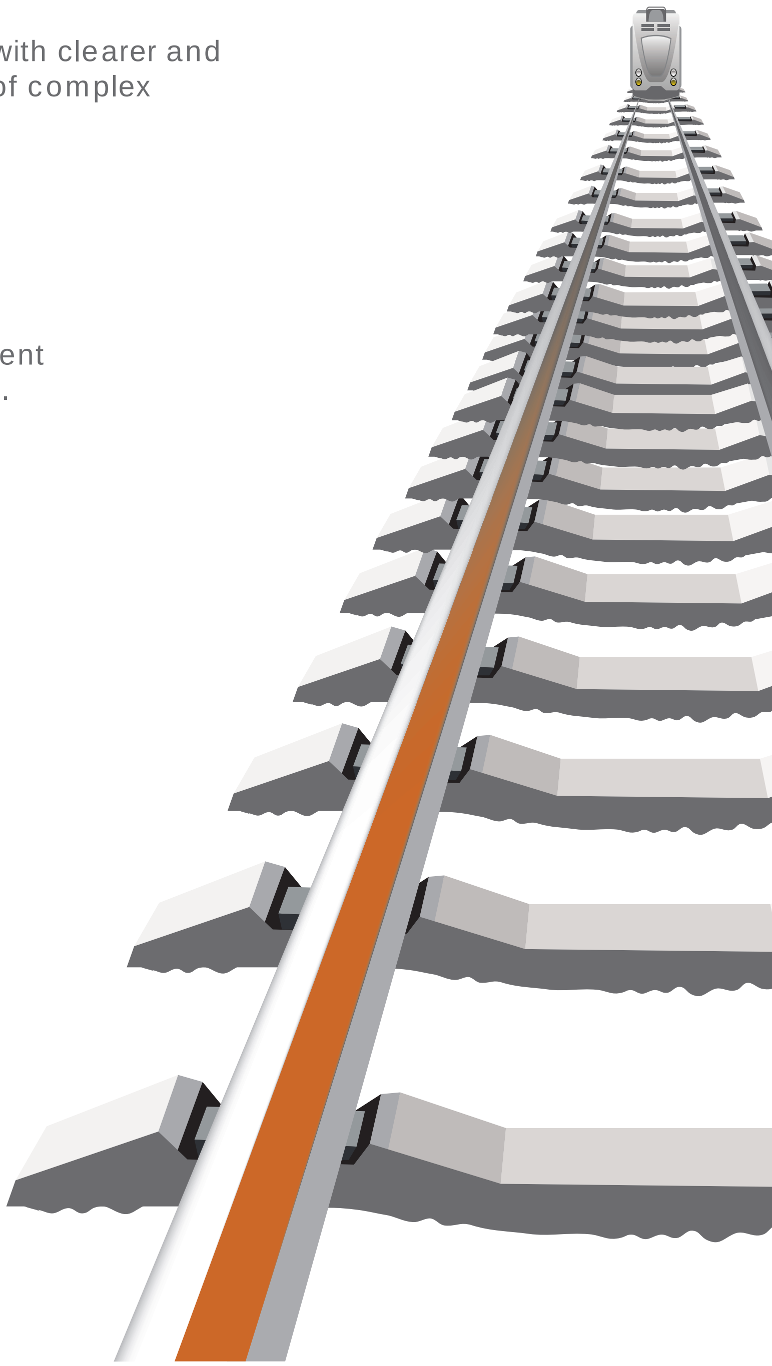
It could better adapt Lean, Kaizen and continuous improvement methodologies to the context of its industry.

REQUIREMENTS MANAGEMENT

It could adopt a scientific approach to requirements and quality management to ensure development is done right every time.

MANAGING COMPLEXITY

And most importantly, it could improve its development processes to better handle complex systems and put every part in the context of the whole.



We feel that it's time to talk about different ways the rail supply industry can approach big-picture thinking in engineering, and this white paper is the result.

SEEING THE WHOLE CUSTOMER

Trying to keep all your rail stakeholders in mind can be a never-ending task. By the time you've got to the bottom of the list, the top of the list has probably changed, and several more people will have come out of the woodwork, axes to grind at the ready.

But when you're developing complex systems that have to integrate into a broader network, involving all your stakeholders at a very early stage can be absolutely critical for the success or failure of a project.

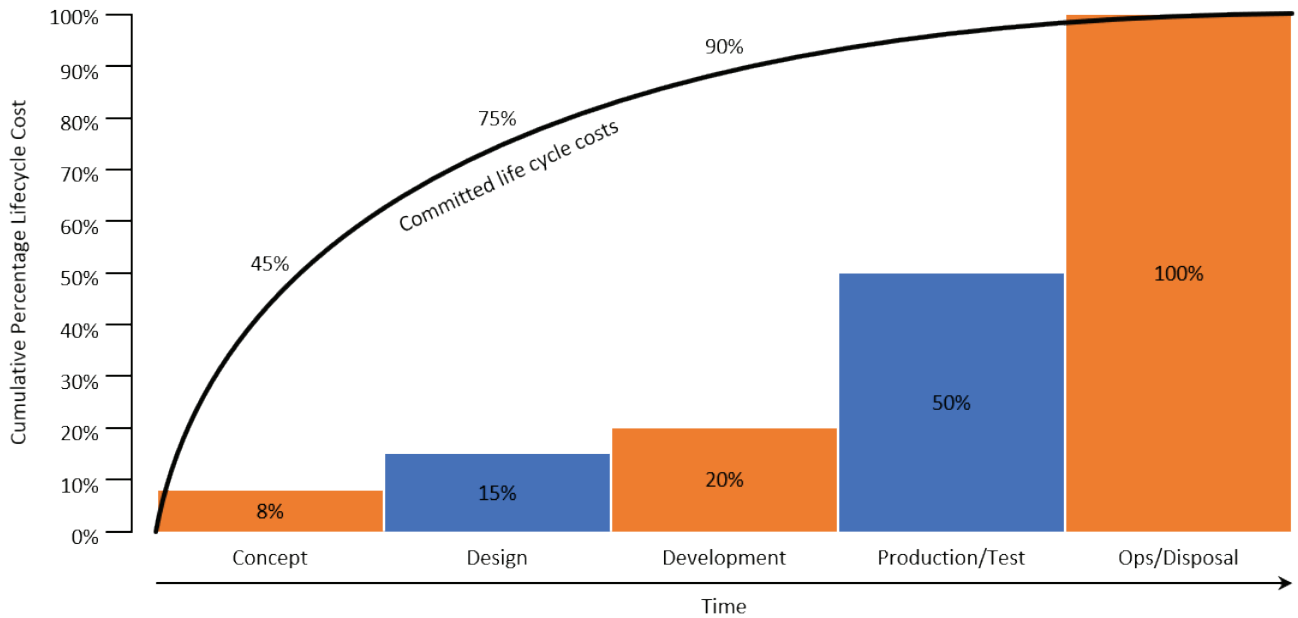
According to the Project Management Institute's global 2019 'Pulse of the Profession' study,[1] project managers in manufacturing industries overwhelmingly report inaccurate requirements gathering, and poorly defined opportunities and risks, as the primary causes of project failure.

Therefore, getting all of your stakeholders on board – and more than that, understanding what they really want, and sorting the necessary from the dispensable – is increasingly seen as a critical mitigation of risk as projects become more complex.

The later in the project your requirements change, the more expensive that change will be, and those costs start accumulating very quickly. As the diagram below shows, life cycle costs of an engineering project tend to get locked-in early in design and development, even if not yet expended. This can rapidly multiply the cost of changing design direction at a late stage. Naturally, this leads to budget and timetable overruns, or even cancellation.

Of course, getting to grips with this in the rail industry is no easy task. The customer is not just the immediate buyer, depending on what you're building, a whole view of your rail industry customer could include: the Rail Safety and Standards Board (RSSB); multiple Network Rail routes and regions; an end-user operating company; a rolling stock company; a wide variety of government and regulatory bodies; passenger groups, and many more. There's no magic bullet which can eliminate the need for these wide-ranging conversations.

But what do exist are processes, skills and tools which can help project managers and others conduct this dialogue more efficiently, comprehensively and with scientific rigour.



Adapted from NASA Systems Engineering Handbook SP-2016-6105 (2016).

[1] PMI (2019). Research Highlights by Industry and Region 2019.

CASE STUDY
THE CHINA STAR

Why a Broad View of the Customer Matters

The turn of the millennium was an era of bold progress in the Chinese rail industry. Led by now-disgraced Minister of Railways “Lunatic Liu” Zhijun, an ambition was formed to transform the country’s network for high speed, using primarily home-grown design.

The China Star DJJ2 was a product of that ambition. With then-Vice Minister Liu determined to create a sensation by achieving high speed passenger travel as soon as possible, engineers were working around the clock. In November 2002, the China Star made headlines when it reached 321.4 kph. Industry observers were astonished. In just five years, Chinese engineering had achieved what had taken other countries decades; getting from 200 to 300 kph. The project was hailed as a huge success story, until the trains were actually due to enter commercial use.

Because of signal system mismatches, and problems with the electrical and braking system, the trains didn’t enter passenger service until 2005, and were limited to a top speed of 160 kph. The problems persisted in service, and by August 2006 the China Star had been discontinued.

The China Star project had been driven by a narrow vision, received from a small group of single-minded stakeholders, and as a result, what was supposed to be a great leap forward, became an expensive waste.

Speaking Clearly

Building a broad view of stakeholder needs and translating that into formal, scientifically rigorous requirements, doesn’t just reduce the risk of project failure, it can have dramatic benefits for efficiency as well.

For one thing, it can revolutionise your own procurement and lead to much more straightforward relationships in your supply chain.

Every business finds themselves dealing with suppliers who seem to find any way they can to misinterpret your instructions. The solution to this has always been to find a way to standardise requirements across the supply chain, and with the right skills and cutting-edge cloud-based tools, it is much easier to do this than it has ever been.

Clear requirements can break down walls within your own organisation too. Quality managers will thank any designer or engineer who is able to specify product requirements in a scientifically robust manner: concisely; consistently; and especially with clarity in what success looks like and what standards need to be met to avoid failure.

As rail engineering becomes more complex, and the big picture becomes harder to focus on, high performance in requirements engineering will only become more important. The techniques to achieve this have been established for some time in other industries, and have their own International Organisation for Standardisation (ISO) standards. It may be time for the rail supply industry to adopt more of these practices.

SEEING THE WHOLE PRODUCT

As rail systems become more complex, the whole is becoming more and more than the sum of its parts. Different components in the network interact in increasingly complicated ways. Keeping sight of the big picture is critical, but engineering doesn't always have the tools it needs to do that.

All rail products exist as part of a larger system, and successful rail engineering needs to understand not just how its product fits into that system as it stands, but how it will react as the system changes in the future.

The introduction of cab signalling shows that even rolling stock needs to be able to adapt to the changing systems of the network, to say nothing of future pressures from accessibility and decarbonisation.

Network-wide systems like control, command and signalling, also have a great deal of complexity and emergent behaviour in their own right, and exist in a constant state of flux, never more so than now.

The risks of engineering in an environment like this are huge, especially because without proper consideration of the emergent properties of the system as a whole, a defect in a new product may not emerge until after it has already been integrated into the network.

The best way to mitigate these risks is, naturally, to find a way to anticipate such problems before they arise, and use a development process which is designed around seeing its output, not as an isolated component, but rather as a detail in a big picture.

Engineering processes that focus on the detail need to be complemented by an approach that, first-and-foremost, is concerned with the system as a whole.

Systems engineering is a discipline in its own right, concerned precisely with the insights, processes and tools to enable you to look at a product in this way.

Systems engineering is about drawing on the science of finding patterns in organised complexity, and the analysis of the emergent properties of a whole, rather than the specific behaviour of individual components. It's a fundamental shift in perspective, based on the idea that looking at the structure of a complex system gives you a better understanding of how the system will behave than you would get from focusing only on the mechanical details.

Therefore, a model of a system as such can treat the parts of the system as black boxes, 'system elements', which take their inputs from their environment and produce outputs. These 'system 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.

These models are generally built from the top down, defined first in terms of broad stakeholder needs. As requirements get clarified and detailed, the model progresses down equivalent layers of complexity, at each stage fundamentally treating subsystems and individual elements as black boxes that transform inputs into outputs.

As such, using a systems engineering model allows the behaviour of the system as a whole to be anticipated prior to proceeding with development. In rail systems, where components are so heavily integrated into a network with complex behaviour, this can be a critical mitigation of risk.

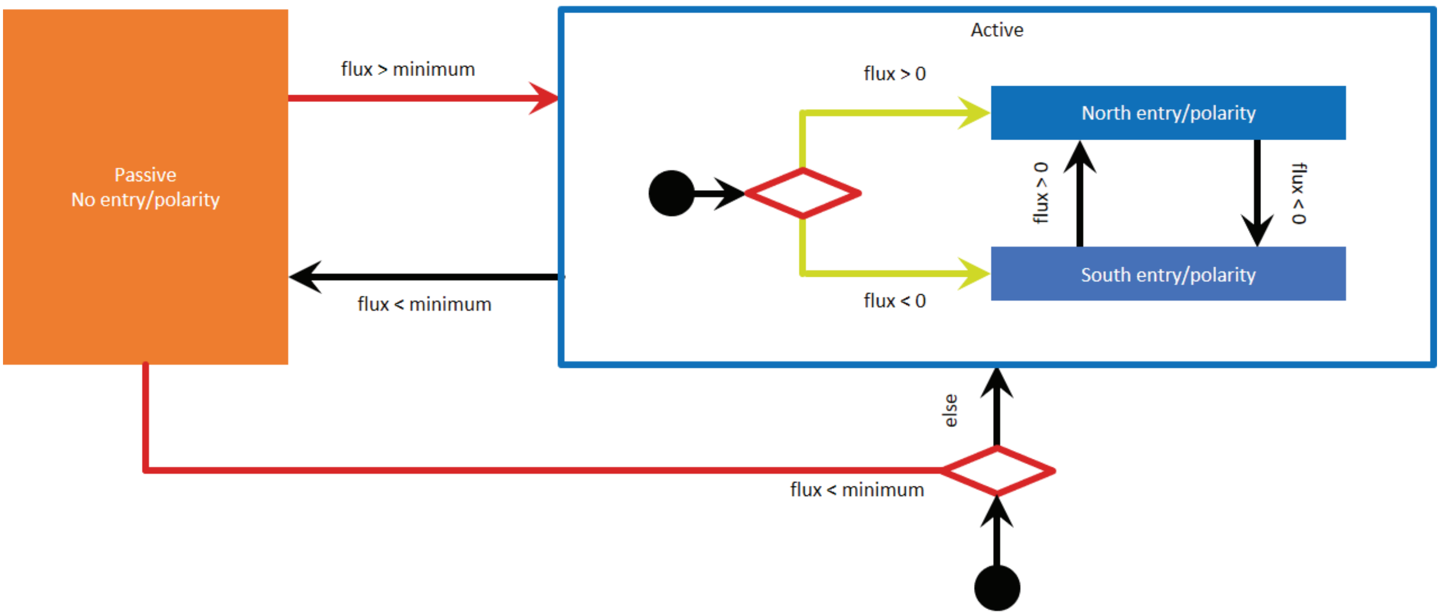
Planning for Change

Manufacturing and engineering production methods like Lean and Six Sigma are effective at reducing waste and providing assurance throughout the manufacturing process, but providing similar assurance during the development phase requires a different set of tools.

A global study by the Project Management Institute (PMI) found that for every pound spent on projects and programs, 5.1 percent is wasted due to poor requirements management.[2]

The techniques and processes of systems engineering, especially the ability to model complex systems early in development, can reduce this waste considerably.

SE Model of an AWS Ramp System



Adapted from "Verification and Validation of a new type of Railway Signal using MBSE and Simulation", Stephenson, Vine & Towers, November 2018.

[2] PMI (2019). Research Highlights by Industry and Region 2019.

But the advantages don't stop there. For one thing, Systems Engineering (SE) modelling and requirements management can significantly improve your relationship with your own supply chain by introducing a single source of truth, and clear specifications, which can be passed down to suppliers in a traceable way. But, the main benefit of an SE model in the long run, is how easy it makes it to plan for change.

Stakeholder needs can change at any point in the product life cycle, either during development or as part of a mid-life upgrade to the system.

By developing and maintaining an SE model, your organisation could 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.

SE modelling requires appropriate technologies to support engineers, but those technologies are already very mature, thanks to industries which have been using systems engineering techniques for some time.

As rail continues to become a more complex environment, the rail supply industry could benefit from using SE modelling in its work.

CASE STUDY

THE SWORD PROJECT

How Modelling Can Produce Better Rail Systems

Network Rail's 'Digital Railway' programme is a large-scale overhaul of the entire network's Control, Command and Signalling (CCS) systems, with the potential to hugely increase the safe capacity of the network while reducing cost.

The programme will ultimately replace every line-side signal on the network with cab signalling systems, but in the meantime, some existing infrastructure will reach the end of its life and require immediate replacement.

The SWORD (Self-powered Wirelessly Operated Distant) signal project was the result of exploring cost-effective options for these 'temporary' signals. The idea was to remove the need for long lengths of fixed copper cable between the signal and its control point.

At the time, model-based systems engineering and simulation-based validation were relatively new approaches to Network Rail and CCS, but there was a need to verify and validate the SWORD system more quickly, cheaply and safely than would have been possible with a traditional prototype.

By building a systems engineering model of SWORD, Network Rail was able to validate the system through simulated testing, produce a better specification for stakeholders, ensure end-to-end traceability of the system, and maintain an adaptable model for any future specification changes.

SEEING THE WHOLE TEAM

Keeping everybody in the loop in rail engineering used to be much easier. But, as stakeholders demand better technology, greater assurance and more integrated systems, the process of sharing information and ensuring traceability can become very tedious, and prevent you from applying skilled engineers and valuable resources to tasks that use their full potential.

Even before you think about external stakeholders and your own supply chain, supplying to the rail industry involves the input of multiple functions and capabilities. Product, design, development, manufacturing, quality, compliance and more, will have an input into your process. All of these disciplines have a unique and highly valued set of skills, but as a result of their different perspectives, it can be challenging for them to keep one another's needs in mind.

The big picture matters in your own process, too, not just in terms of how the part of the product any individual is concerned with fits into the whole, but understanding the needs, expectations and process of other functions, can have significant advantages.

In other words, engineering works better when it's more joined up. It comes down to effectively sharing information between teams, but as the rail industry becomes more complex, rail supply and engineering will have to look at different ways of making this practically achievable. What this would mean is moving past ad hoc communication between teams – passing emails, documents and spreadsheets around the organisation – and towards a way of handling shared information with respect for the needs of other functions inherently built in.

Such an approach would need product and task information to be specified in a standardised format that is designed to meet the needs of everyone expected to use that information. It would also need to be responsive to change, and enable seamless propagation of any updates to project goals, specifications or standards across all engineering functions, while keeping everyone on the same page by guarding against errors, miscommunication and poor traceability. When you put it that way, you wonder if the best way to think about sharing information is 'communication' at all. Communication implies two separate stores of knowledge interacting. When in fact, all your engineering functions could be working from a single source of truth. A big picture that is being constantly maintained, adapted and used by everyone involved, which requires them to think about the needs of others by virtue of how the information is structured. By setting things up this way, you can significantly diminish the burden on engineers to spend time communicating effectively and traceably. And at the same time, you can make sure everyone's information is accurate, up-to-date, secure, traceable and as complete as they need it to be.

Breaking Down Walls

Joined-up development undoubtedly needs the right tools to support it, but those tools are only as valuable as the skills of the people operating them, and the processes that need to be put in place. This is what makes the difference between teams that grumble about an additional layer of compliance, and teams that feel enabled to do their jobs better by the tools provided to support them. Thinking in terms of the big picture is more than a cast of mind; it requires a specific set of skills. Embedding those skills throughout your organisation can make your development process considerably leaner and more effective, while enabling project managers to focus on what really matters.

Giving your teams the skills that they need not just to use, but also to understand the value of, your tools can be critical to ensuring you derive value from your investments. No tool can replace the value of understanding the needs of the people whose work interacts with your own, but having that big-picture understanding can make the difference between a successful process innovation and an expensive burden.

CASE STUDY
INVENSYS RAIL DIMETRONIC

Implementing European Rail Traffic Management System (ERTMS) signalling is a safety-critical smart railway project underway throughout Great Britain and set to take up to 30 years.

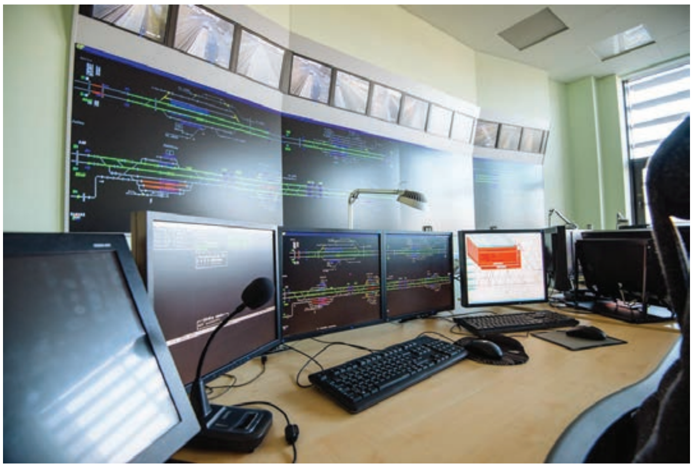
Invensys Rail Dimetronic was involved with the development of the underlying systems from a very early stage, and wrote around a million lines of code in the course of those projects.

That code was handled by multiple teams spread across global locations, so making sure everyone was on the same page was an extremely challenging task.

By implementing tools which enabled them to maintain a single source of truth – in their case, a precursor to IBM® Engineering Lifecycle Management – they were able to streamline information sharing considerably.

Using these tools enabled them to reduce time-to-market by up to 40 percent, and by moving away from manual testability and traceability, they were able to focus their people and resources on product goals like safety, instead of more tedious tasks.

A single source of truth also allowed them to be sure that what they were doing at the highest levels was integrated with the lowest levels, provided people with real-time access to information, obtained very accurate and personalised reports about the state of the project, and linked project requirements directly into the code.



Invensys Rail Dimetronic: cutting time to market by 40 percent with a single source of truth.

SEEING THE WHOLE LIFE CYCLE

Engineering for the rail industry has always required thinking about the long term. 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 future-proofing your own designs, is always a difficult balancing act, and the rail industry has to think in longer time horizons than most.

Rail systems aren't just getting more complicated because they need to do their existing job better; the future is (rightly) making greater demands of the present than ever before. In rail, work to meet a net zero carbon target by 2050 needs to begin very urgently.

Accessibility needs to accelerate to accommodate an aging population and make up for the failings of the past. As the world around us gets smarter through the Internet of Things, rail needs to be able to adapt. Understanding the demands that these trends place on your systems, is part of the answer.

Lofty strategic thinking and the ability to forecast the future plays its role, but at the level of an individual rail project, engineering for change comes down to questions of efficiency and risk. *How can I stay on time and on budget when the goals of the project keep being updated? How can I create a design which encompasses the broad demands of these trends and adapts to the unknown? How can I ensure quality when the utility of my system depends so much on the ever-changing environment around it?*

What systems engineering brings to the table in rail, is a view of the system as a whole, and in its context, and how the structure of this 'system-of-systems' will generate its behaviour. The outputs of the whole system, in terms of passenger and other user satisfaction, the operating environment and interaction with other systems – in short, the value derived from the whole system throughout its life cycle – are at the front-and-centre of quality.

Ensuring quality throughout the whole life cycle of a product is baked into systems engineering and the tools that support it. A huge part of that is in its scientific approach to requirements engineering, which generates specific, unambiguous and testable requirements using the same method as a scientist uses to generate the hypothesis of an experiment. Black box models of how the elements of a system interact with one another, also significantly reduce the risk of an emergent defect not being detected until the system has been integrated. But really, thinking about quality like a systems engineer is about thinking in terms of a hierarchy of complexity, in a way that begins and ends with the big picture of the system.

A systems engineering development process starts with the broad needs of the client, turns that into specific requirements for the system as a whole, creates an architecture at the system and then the subsystem level, and only then produces a detailed design for the individual elements.

Ensuring quality of a whole system is about going through that hierarchy in reverse: testing the reliability of individual components or modules against specifications; verifying the performance of subsystems against requirements; then validating the outputs of the system in terms of customer need. This is coupled with a clear recursive process for when standards are not met, to ensure definitions are revisited at the most specific level possible.

The effect of all of these processes is to dramatically reduce change latency in an engineering project. Major rail industry players like Network Rail have been directly applying systems engineering techniques for some time, but those techniques have not yet reached much of the rail supply chain.

It may be time to consider that the ever-increasing complexity of rail systems requires everyone involved to have an eye on the big picture.

Right from the Start

Systems engineering allows the rail supply industry to take a whole life cycle view of its products, and better understand how they integrate with the rail network as a whole. It has a strong focus on good practice in requirements engineering and using that to develop models of a system which can be used for simulation and anticipation of potential emergent issues, ahead of time.

In other words, systems engineering is about getting it right from the start when you're dealing with complexity. It comprises a series of processes and techniques for analysing the properties of a whole as more than the sum of its parts, but more than that, it is a way of thinking about a project which keeps focus where it should be - on how what you're doing fits into the big picture.

Systems engineering needs the right skills, the right process and the right tools. But with these in place, rail supply could respond to the complex challenges of the industry's ever more demanding needs by enhancing the efficiency of its process, and reducing project risks.

The opportunities are there for the taking, and big-picture thinking is there to help the rail supply industry meet them.

CASE STUDY

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. 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. 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 suggest 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

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The China Star case study is compiled from various news articles.

The 'SE Model of an AWS Ramp System' diagram is adapted from an academic paper freely available online. Written by Network Rail and a consultancy as a submission to an INCOSE conference.

The SWORD project case study is adapted from that same paper.

The Invensys Rail Dimetronic case study was adapted from one of IBM®'s own case studies for selling DOORS®.

The East London rail extension case study was synthesised from two case studies prepared by the INCOSE Transportation Working Group. These case studies are freely accessible online.

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