Building a Systems Engineering Framework for London Overground using Experiences from the East London Line Project (ELLP)

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Abstract.

London Overground is a passenger rail service under the responsibility of the Mayor of London, which is managed by Transport for London (TfL) and is operated by London Overground Rail Operations Limited (LOROL). London Overground forms part of the UK national rail network and Network Rail is the Infrastructure Manager (IM) as defined under the UK railways regulations except for a relatively short section of the East London Railway (ELR), for which Rail for London (RfL) is the IM. The current plan is for RfL to extend its IM duties to new routes such as the extensions of the ELR and to parts of the Crossrail route. The £1bn East London Line Project (ELLP) was responsible for the development of the ELR and the innovative Systems Engineering practices employed on that project have been reported in previous papers.

This paper consolidates the experiences and knowledge from the ELLP into a number of ‘lessons learned’. It then proceeds to describe how the development of a framework of systems engineering practices for RfL’s new IM role has benefited from the experiences on the ELLP.

Introduction

Figure 1: London Overground (Orange twin line) with London Underground Map

London Overground is a passenger rail service under the responsibility of the Mayor of London, which is managed by Transport for London (TfL) and is operated by London Overground Rail Operations Limited (LOROL). Represented by a new symbol (the orange roundel), London Overground adds main line rail to the TfL family of modes (which includes underground, light railway and trams) and sets new standards in train travel, helping more people to move more easily into and around London.

The London Overground network currently consists of four linked lines i.e. the North London, West London, Gospel Oak to Barking and Euston to Watford. TfL have just completed the construction of a new line, the East London Railway (ELR) and are currently in the test and commissioning stage of Phase 1 of the project known as the East London Line Project (ELLP).

An extension of the ELR known as Phase 1a, which links the ELR to the North London line, is currently under construction and a further extension, known as Phase 2, in the south of London will complete the orbital railway around the Capital.

One of the most exciting developments that has taken place as a result of the launch of London Overground is the introduction of new trains. These modern and accessible trains have replaced a rather old and neglected fleet. They have been designed to cater for the high volumes of peak time commuter traffic on the busy commuter routes of the London Overground network. The new air conditioned fleet offers a metro style layout with a unique seating arrangement to provide more space for passengers.

Figure 2: Class 378 Rolling Stock – Both AC and DC variants exist for different traction power systems on the LO network and the interior is designed for high capacity and accessibility

London Overground forms part of the UK national rail network, run as a franchise by the train operating company LOROL, and the Contracting Authority is TfL rather than central Government. Network Rail is the Infrastructure Manager (IM) as defined under the UK railways regulations for the London Overground network except for the Dalston to New Cross section of the ELR, for which Rail for London (RfL) is the IM. The current plan is for RfL to extend its IM duties to new routes such as the extensions of the ELR and to parts of the Crossrail route.

This paper consolidates the experiences and knowledge from Phase 1 of the ELLP to inform the development of the systems engineering framework to be applied on the development projects to be undertaken by RfL as an IM.

The Need for a New Engineering Framework

Phase 1 of the ELLP has added a new railway, the ELR, to the London Overground network, which has a complex arrangement of asset operators and owners as illustrated in Figure 3. The assets on the section north of New Cross Gate are mainly owned by RfL (also referred to as London Rail (LR)). As LR are also the IM for this section (referred to as the ‘core route’) and it is the first part of the national rail network for which it will have that responsibility, they needed to establish the associated organisation, employ competent people and engage competent contractors to achieve the necessary safety certification and authorisation so that they could operate the new railway. Part of this organisation provides the engineering services that continue to develop the London Overground network and therefore a new engineering framework was developed to provide these services efficiently and effectively.

The London Overground infrastructure is owned, operated and maintained by a number of different parties with different strategic plans for their businesses. Figure 3 below shows the complex arrangements in place for the ELR. The section around Surrey Quays is typical of the remainder of the London Overground infrastructure. Currently RfL is only IM for the section of the network from Dalston Junction to New Cross on the Core Route, part of which was previously owned and operated by London Underground.

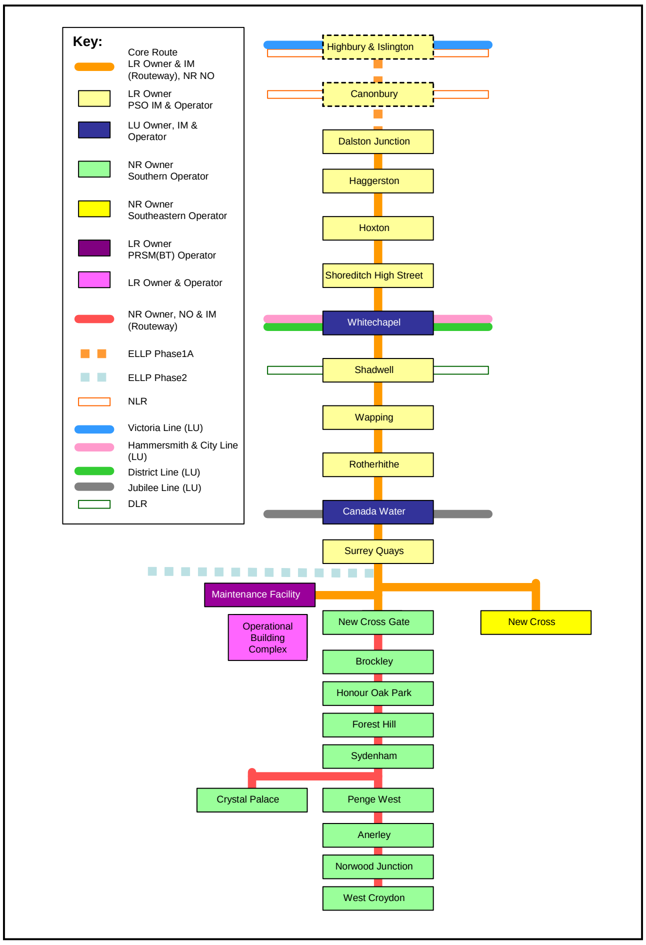

Figure 3: Section of LO Route showing ownership/responsibility

In March 2008 the responsibilities of the Infrastructure Manager (IM), under the Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) (including the Network Operator role under the Railways Act), on the Core Route of the ELR were transferred from London Underground (LU) to London Rail (LR). Figure 4 provides an overview of the current organisation.

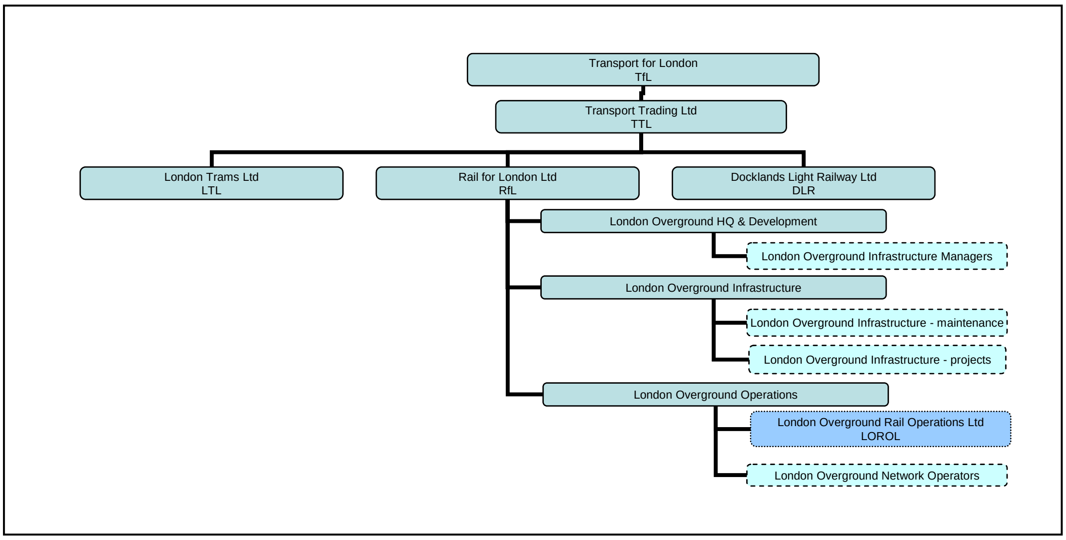

Figure 4 – Organisation showing allocation of IM and Operational responsibilities

While the day-to-day maintenance activities are expedited by the Maintenance division, the Projects division of the London Overground Infrastructure (LOI) organisation is responsible for the capital works and developments for the LO infrastructure. This includes projects that are developing the North London railway and extending the ELR, such as the ELLP Phase 1a and Phase 2. It is this organisation that uses the framework described in Section 4.

LOROL, managed by TfL, is responsible for the operations of the passenger service on all London Overground routes and therefore performs the function as Station Operator on many of the stations. However at interchange stations with London Underground and where the majority of the trains are operatied by another Train Operating Company (TOC) this responsibility lies with others. LOROL is a 50:50 joint venture company between the Hong Kong rail operator MTR Corporation and the German rail operator DB Regio, a subsidiary of Deutsche Bahn.

Lessons Learned from ELLP

The systems engineering techniques for the ELLP have been the subject of previous papers (see references). This section explains some of these practices and the lessons learned during their development and use that have influenced the engineering framework for LOI projects that is explained in the subsequent section.

Aligning the Lifecycles

The Project Lifecycle and System Lifecycle applied to the ELLP are shown in Figure 5.

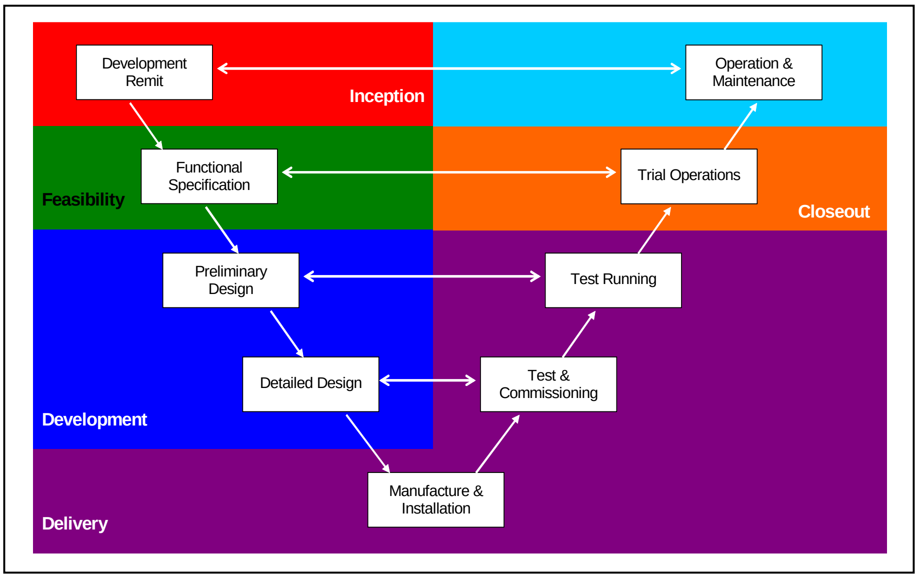

Figure 5 - Project Investment & Systems Lifecycles

The background blocks define the Project Investment Lifecycle stages whilst the ‘V’ shaped lifecycle represents the high ‘system’ level engineering activities of the Project and indicates the relationship between the specification of the system (left hand side of the ‘V’) and the integration and test of the system once built (right hand side of the ‘V’).

The system ‘V’ lifecycle in Figure 5, however, did not reflect the complexity of the system breakdown so a more detailed lifecycle was developed from an analysis of industry models. Whereas traditional technical lifecycles usually take an approach from one particular viewpoint (e.g. RAMS (Reliability Availability Maintainability Safety), systems engineering, software development, infrastructure development or manufacturing) the ELL System comprised all these aspects plus scope to deliver operational products (e.g. trained drivers, procedures, facilities, service agreements, etc.). The ELLP Engineering Lifecycle that was developed had 10 stages with associated stage gate reviews and configuration baselines as shown in Figure 6.

Lesson 1 – Selecting the Right Lifecycle

We have found that there are nearly as many views on which lifecycle should apply and what the stages in each lifecycle actually mean as there are engineers on the project. Standards for one organisation are different to another due to each's particular role and business model and every discipline seems to have its different perspective. The ELLP attempted to solve this by clearly defining the relationship between the TfL business' investment lifecycle and the System Level 'V' lifecycle and then defining an Engineering Lifecycle that could be related to the System Lifecycle and applied consistently across the project and for every level of system breakdown. It is vital therefore to select or develop an appropriate lifecycle for the scope and subject of the project and to clearly define how it relates to all other lifecycles that might be applied. The ELLP was special because it needed to deal with the development and production of railway infrastructure (fixed assets), rolling stock and operational items; not all projects will need a lifecycle that is so versatile.

Once established, the lifecycle can be used as the basis for the structure of the project's Process Management System. If this is the case then it is doubly important to have a generic lifecycle and to be consistent in its use from start to finish of the project i.e. throughout its lifecycle.

Lesson 2 – Maintaining the Principle
Once defined the lifecycle must be communicated to all through an appropriate engineering management plan. It must be understood by all and most importantly, used by all. It is vital to ensure ownership of the principle within the project and to ensure knowledge is maintained as key staff change during the course of the project – continually bringing in their traditional views to challenge the defined way.

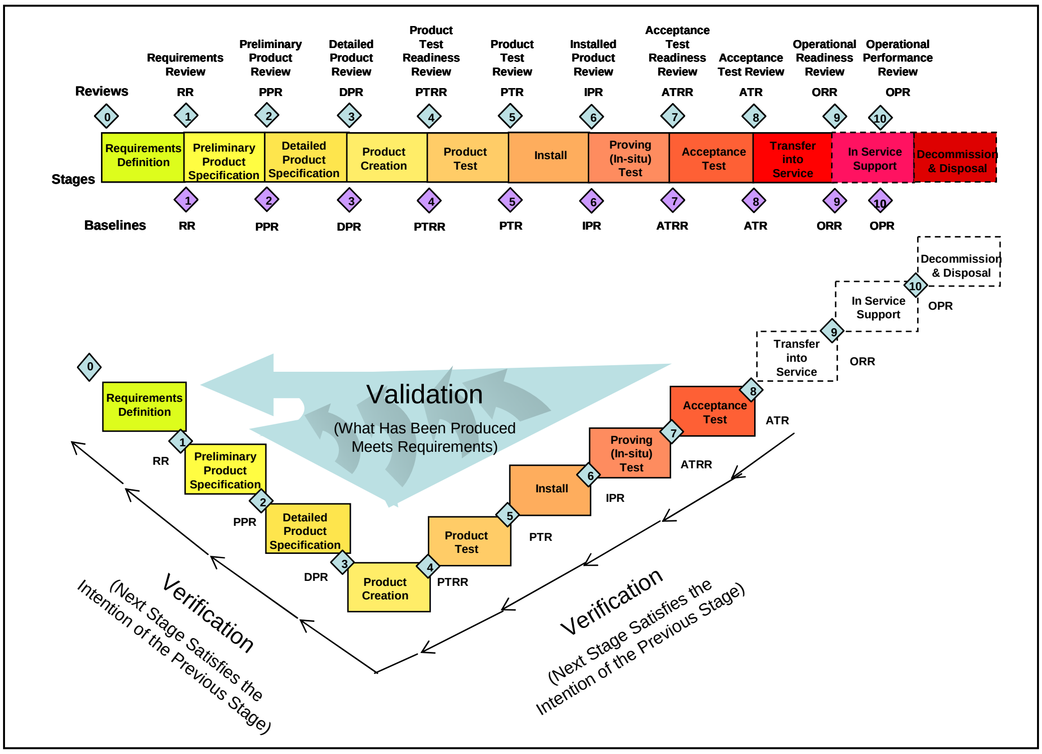

Figure 6 - Engineering Lifecycle for all Levels of the ELL System and the Definition of V&V for the ELLP

Delivering Progressive Assurance

A significant factor in the complexity of the ELLP was due to the large number of stakeholders. Having a number of stakeholders needing to accept all or parts of the project products brought many challenges. To address the risk associated with non-acceptance of the ELL System by one or more of the stakeholders the project team spent some considerable time developing an overall progressive assurance strategy and plan to ensure the acceptance process was carefully thought through and planned. The resulting ‘Progressive Assurance’ approach resulted in the routine production, review and approval of assurance evidence as the Project progressed through its lifecycle stages at every level of the system breakdown.

System acceptance was planned and agreed before the Project proceeded to the product development stages. The assurance evidence was presented as part of ‘technical cases’. These provided a complete and robust argument that the Project’s technical products complied with the requirements and the appropriate processes had been followed. The assurance arguments and evidence were presented in a hierarchy of technical cases which reflected the logical breakdown of the ELL System. It is important to note that Progressive Assurance was applied, and the technical cases were delivered, in conjunction with the use of established engineering and assurance processes.

Each technical case comprised arguments supported by evidence that demonstrated an objective had been met and also tables referencing the documentation that provided the evidence. The technical cases were developed using a technique based on the Goal Structuring Notation (GSN), after Kelly & Weaver (see reference 1).

The technical cases were developed as a hierarchy reflecting the ELL System breakdown as shown in Figure 7 and were produced progressively; building up into the overall technical case for the ELL System, the Level 1 Technical Case. The Level 1 Technical Case therefore depends upon, and makes reference to, many other technical cases at lower levels.

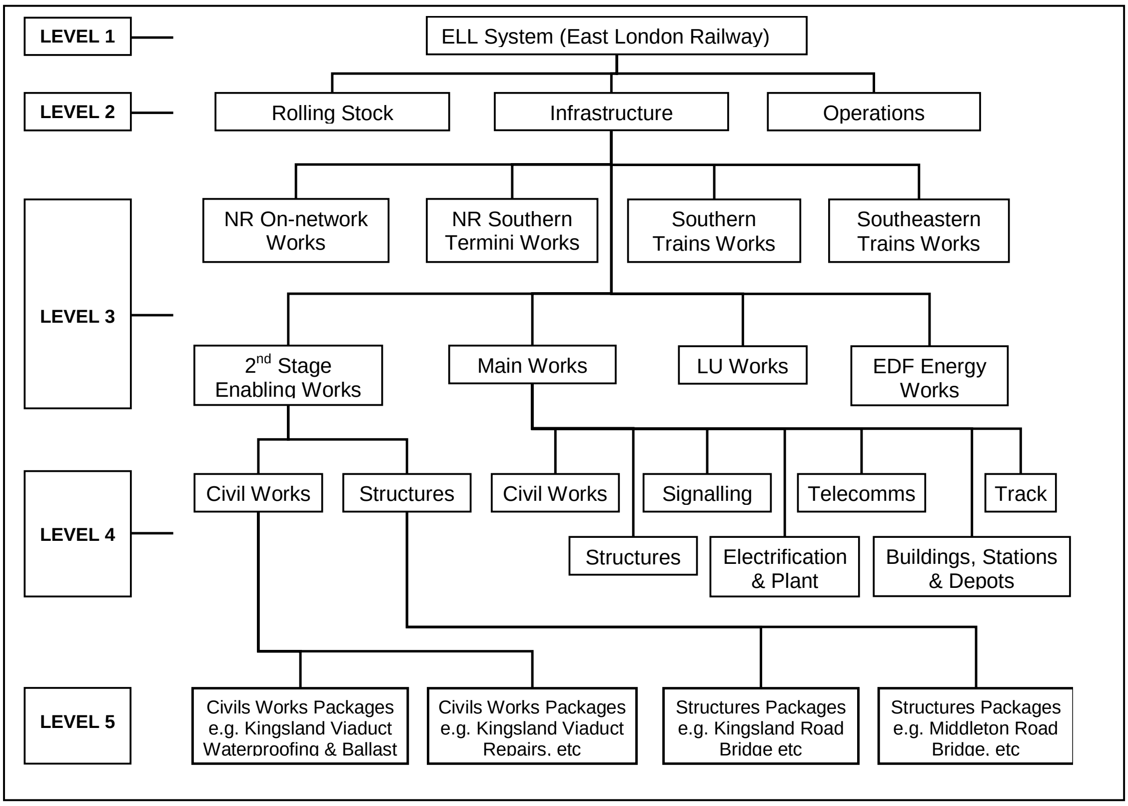

Figure 7: - The Technical Case Hierarchy reflects the ELL System breakdown

Lesson 3 - Keep it Simple

The rigour of the Technical Case (TC) structure selected has greatly helped to produce a comprehensive set of arguments. However it has been found that, if not applied with continuous attention to the ultimate objectives and using experienced judgment, it can result in large, detailed TCs with GSN diagrams which cover walls and have so many branches it is difficult ‘to see the woods for the trees’. During the execution of the ELLP the process was continually refined through the lifecycle to ensure delivery of a focused, concise portfolio of evidence. The key lesson here to be applied to future works is don’t use GSN to the nth degree, but use an appropriate level to arrive at an argument that delivers sufficient assurance relative to the risk.

Lesson 4 - Differentiating Product and Process Arguments

When developing a TC it is beneficial to look for similar arguments or pieces of evidence that are used in more than one place and to consider whether an alternative structure would simplify the argument and reduce the size of the TC; both of which tend to make the result more comprehensible to stakeholders. One technique used mid-way through the ELLP was to adopt a Process, Tools and Competence (PTC) TC as shown in Figure 8. These then contained the assurance argument and evidence associated with the processes used, the tools (e.g. software/applications) used and the competence of staff employed. Thus the product argument and evidence is focussed on the characteristics and scale of the particular railway being specified and delivered.

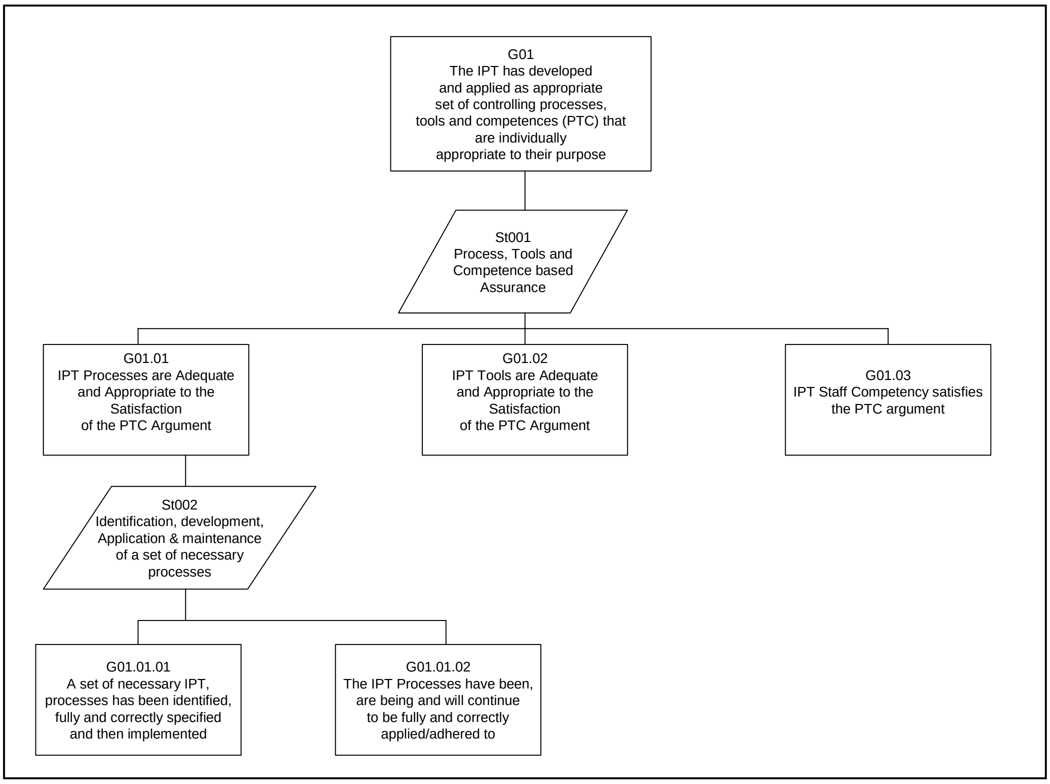

Figure 8 - Top Level PTC Argument Structure

Lesson 5 - Traffic Lights for Monitoring

It has been found that the TC GSN diagram can be a very effective way of presenting progress of a complex multi-level system and multi-party project. Colour coding the diagram, such that goals and solutions turn from red to green as evidence is filed and arguments are completed, gives an immediate snapshot of the where the project is along the engineering lifecycle associated with the product of that TC. The same for the Process TC, the colour coding will indicate how well-established and effective the project quality management systems are. This was implemented successfully on the ELLP to apply a focus to the delivery of the project’s assurance products.

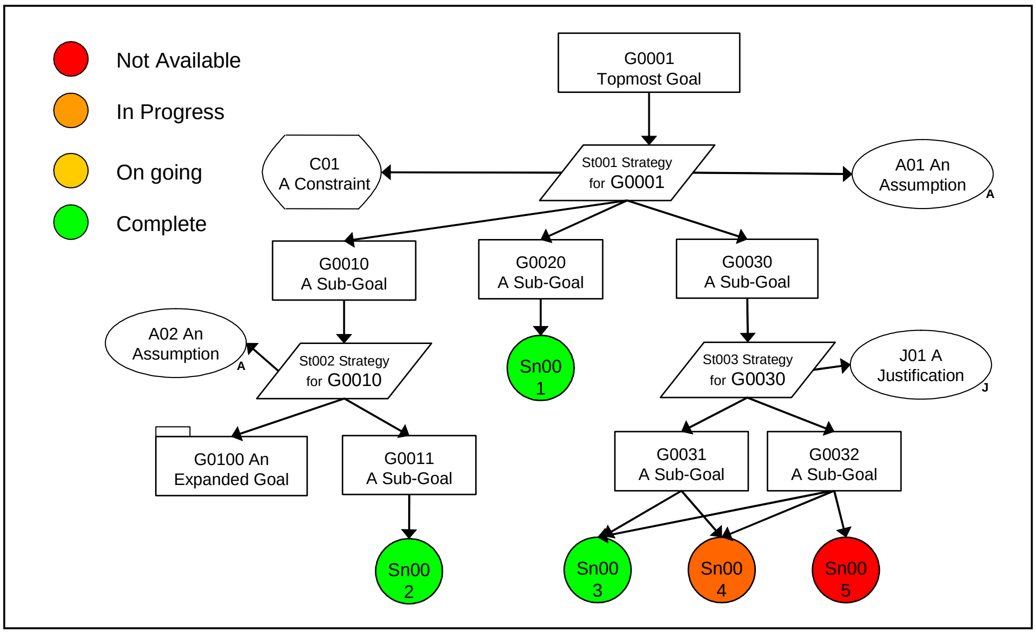

Figure 9 - Colour Coded GSN illustrating status of assurance evidence

Lesson 6 - Argument details to be relative to level of risk

The rigour applied to the argument development must be focused on the degree of safety risk associated with the asset or system. So a risk-based technique was applied for the ELLP. For instance a simple under-track cable route required a reduced level of argument and assurance evidence as opposed to a much more comprehensive argument and level of assurance for a new, large over-track railway bridge that was installed on the busy approach to Liverpool Street station, a main terminus in London. This message has been adopted onwards in such contracts as the Phase 1A Dalston Western Curve civil engineering contract with great success and cost effectiveness.

Lesson 7 - Classification of Evidence

The GSN provides a robust assurance argument. The limitation however is that this system applied equal importance to each and every piece of assurance evidence identified. During execution of the ELLP some refinement was applied to classify the evidence relative to its importance and the degree of assurance it delivered. This applied in conjunction with the classic GSN categorisation of direct evidence and backing evidence resulting in the framework shown in Figure 9.

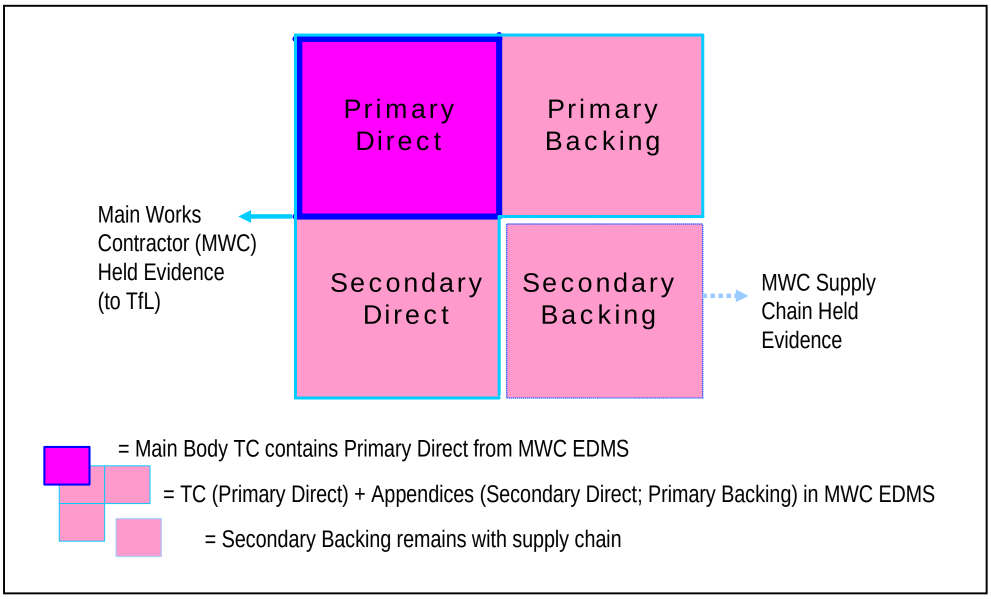

Figure 9 - Evidence Category Model for Technical Cases

Lesson 8 - Integrated programme for delivery
A definitive list of assurance deliverables that is fully integrated into the master programme or schedule is key to the provision of timely assurance. A key enabler to successful delivery is also to ensure the TC and its associated evidence is built into the contractual payment mechanism. For example at payment milestones associated with the procurement of the rolling stock, a successful stage gate review, etc.

Lesson 9 - Integration of the assurance argument
Reference 2 describes how assurance evidence for the ELLP was collated progressively through the engineering lifecycle and relative to the system breakdown. TfL produced the Level 1 and Level 2 TCs the supply chain provided those at Level 3 and below. To ensure a consistent approach a TC Guidance Note was prepared and issued to all members of the supply chain. Further to this a series of integration workshops were held to ensure the GSN connected up and down to provide a complete argument for the railway system. This model has been further adopted on subsequent projects to ensure a truly “systems approach” to the provision of assurance.

Packaging of Work / Division of Responsibility

Lesson 10 – Appropriate Requirements Management Technology
A Requirements and Interface Management System (RIMS) was utlised by the TfL team for Phase 1 of the ELLP from a railway system level to contract level (Hickman & Moorey INCOSE UK SC07). An exported report from the DOORS® (Dynamic Object Orientated Requirements System) database tool employed by RIMS then formed part of the technical specifications for each of the respective contract packages. Process requirements were then placed on each member of the supply chain to take these requirements and manage them through the lifecycle. The passenger rolling stock supplier used a product called SLATE, while the main works contractor also used a requirements management system based on DOORS. Individual Requirement Satisfaction Reports were generated using these sophisticated tools and systems and these provided the detailed evidence to demonstrate achievement of a requirement that supported the respective TCs. Whilst such a comprehensive approach to requirements management was critical to the success of the large multi-disciplinary ELLP Phase 1, on some of the smaller elements of work that the IM will contract out it is expected that less sophisticated technology could be used, so long as the underlying concepts were maintained.

Lesson 11 - Requirements versus a Design based contract

The Main Works Contract was a requirements-based contract which also contained a suite of Preliminary Design Submissions (Form As) that had been produced in accordance with Network Rail standards (in particular NR/SP/CIV/003 Technical Approval of Design, Construction and Maintenance of Civil Engineering Infrastructure). The contract required the works contractor to follow process in accordance with the NR standard for subsequent stages of the engineering lifecycle. As NR/SP/CIV/003 is not principally a requirements-based process there were some areas of conflict between approaches with additional material required to demonstrate achievement. These additional verification and validation (V&V) activities were embedded into the LOI procedures to be used on future projects.

Lesson 12 – Investing in the System Architecture Diagram

The ELLP had defined a System Architecture which identified systems elements, interfaces and boundaries. The architecture took the form of a layered block diagram showing scope of work and ownership for each functional element of the system. Interfaces were represented by connectors between the elements. Figure 10 shows a section of the ELL System Architecture Diagram that has been progressively built up as the requirements have been detailed and the design and operational concepts have been modeled.

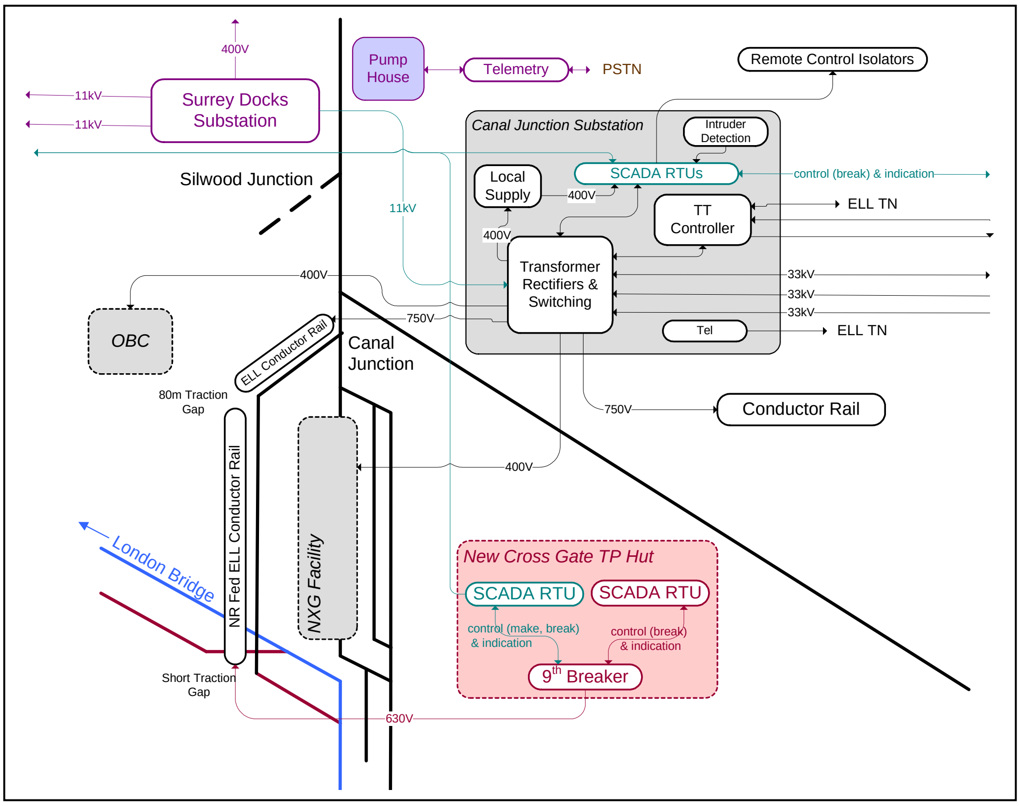

Figure 10 – Partial View of the ELLP System Architecture Diagram

The System Architecture was developed in parallel with the technical requirements and interface registers; this being good system engineering practice. Doing so provided an independent means of visualising the proposed ELL System; that in turn helped to provide reassurance that the system requirements were complete and correct. The System Architecture diagram should be maintained to reflect the railway as it changes during Operations and Maintenance and through capital works and extension projects so that its value is retained.

Lesson 13 – Testing of the Infrastructure

The ELLP Main Works Contractor (MWC) was contracted to lead on integration and testing of the entire infrastructure. The MWC developed his own System Architecture supplemented by particular plans to refine the knowledge for key interfaces e.g. that where the route transfers from RfL owned infrastructure to NR. It was essential to define responsibilities and accountabilities for each of the tests, and the System Architecture diagram proved key in defining this and the logic for the test and commissioning plan. Problematic areas were those where there where multiple owners and where the MWC did not have a direct contractual relationship, however by considering these early with the visual aid of the System Architecture a solution was identified. It is therefore key to work back from the end game of testing and acceptance to define and clarify responsibilities and accountabilities for this and exactly what is required to be produced: the System Architecture can be used a tool to facilitate this.

Process and Documentation

Lesson 14 - Process Compliance

To ensure timely delivery of the finished, assured product on site, it was essential to ensure the engineering processes that had been defined/applied by the various parties were followed. Where this was not so delays were incurred in respect of the completion of technical cases and thus the acceptance into use of the asset or system was delayed. In the interests of maintaining programme on site, a backlog of comments on design submissions in the early stages of the project caused significant problems. In the later stages, and on more recent contracts such as on Phase 1A, these were addressed prior to endorsement of the design submission as should be.

Lesson 15 – Managing a Mountain of Paper

The main output of the first half of the lifecycle (i.e. before product creation) was documentation. With hundreds of documents produced it was essential to have both a good understanding of the relationships between documents and a well managed production, review and filing system. A Document Hierarchy or Tree and an Electronic Document Management System (EDMS) together with robust Configuration Management (CM) were therefore essential assets for the ELLP (see reference 3). The degree of success in obtaining the potential benefits is proportional to the amount of rigour applied to the early establishment and continual maintenance of the appropriate combination of these management systems.

Lesson 16 – Managing the Railway Configuration

Configuration Management was adopted on Phase 1 of the ELLP and process requirements placed on the supply chain to adopt a system that followed the principles of BSEN10007. Originating from the manufacturing industry this technique was applied to an appropriate degree based on the complexity of the sub-systems being delivered. For instance, the signalling and communication systems applied more rigour as opposed to the civil engineering field. It is important to ensure an accurate definition of the delivered Railway Build Configuration (RBC) is obtained by the IM on system handover. Once the configuration of the as-built railway system has been captured in the IM’s documentation management systems and asset information systems it is important to keep the information up-to-date and under control.

Operations and Maintenance

Lesson 17 – Timely Operations Concept Definition

The operational requirements for a railway should be the basis of the technical solution that evolves. On Phase 1 of the ELLP the Operations and Control Strategy and Requirements document defined these requirements for a substantial period of the project lifecycle. As the project made the transition from a feasibility project to a delivery project, the Operations and Control Strategy and Requirements was refined and developed and eventually mature Operational Concepts were defined. The late definition of these fundamental documents resulted in ambiguity in certain aspects of the detail design, e.g. the control centre, which in turn had the effect of major change late in the project. In future projects the Operational Concepts must be defined during the early stages of the lifecycle to avoid costly change late in the project.

Lesson 18 – Informed Asset Management Arrangements

Like the operational requirements there was a lag in the definition of the maintenance requirements for the Phase 1 ELL System. This was in part due to the uncertainty associated with who would be the IM for the various parts of the ELR. Subsequently the generation of an Asset Management Strategy for the project occurred late in the lifecycle. Figure 11 shows the pivotal position of the Asset Management Strategy in influencing and controlling project contractual interfaces and Operations & Maintenance (O&M) organisations' Asset Management plans and processes and so its lateness had an associated cost impact.

One delivered the ELR assets need to be managed so as to achieve the required performance for the life they were designed for and this will require appropriate maintenance regimes to be effected. Future projects should be able to obtain sufficient details about the assets that comprise the London Overground network and their actual performance so as to develop more informed and timely asset management plans for their projects.

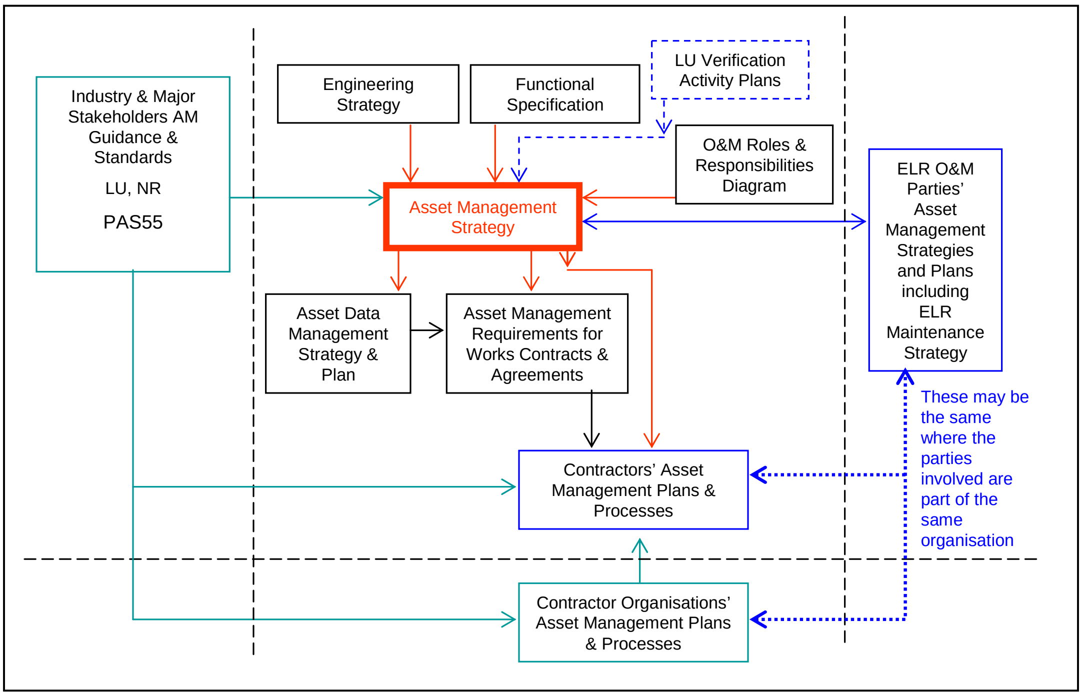

Figure 11 - Asset Management Strategy and relation in transition from a Project to a Maintainer/IM

Engineering Framework for an Infrastructure Manager

Controlling the Configuration

The engineering framework needed for an Infrastructure Management organisation is significantly different than for a one-off engineering project. The IM is primarily responsible for the safe operation and maintenance of the infrastructure, and system upgrades and extensions become a secondary priority. The emphasis shifts therefore from engineering a new or significantly enhanced railway system to that of controlling in safe way the use and change to the existing operational railway within the regulatory and business constraints imposed in the licence. Functions such as Asset and Configuration Management are now the responsibility of the Maintenance team and Risk and Change are managed by the wider LO Business Services team.

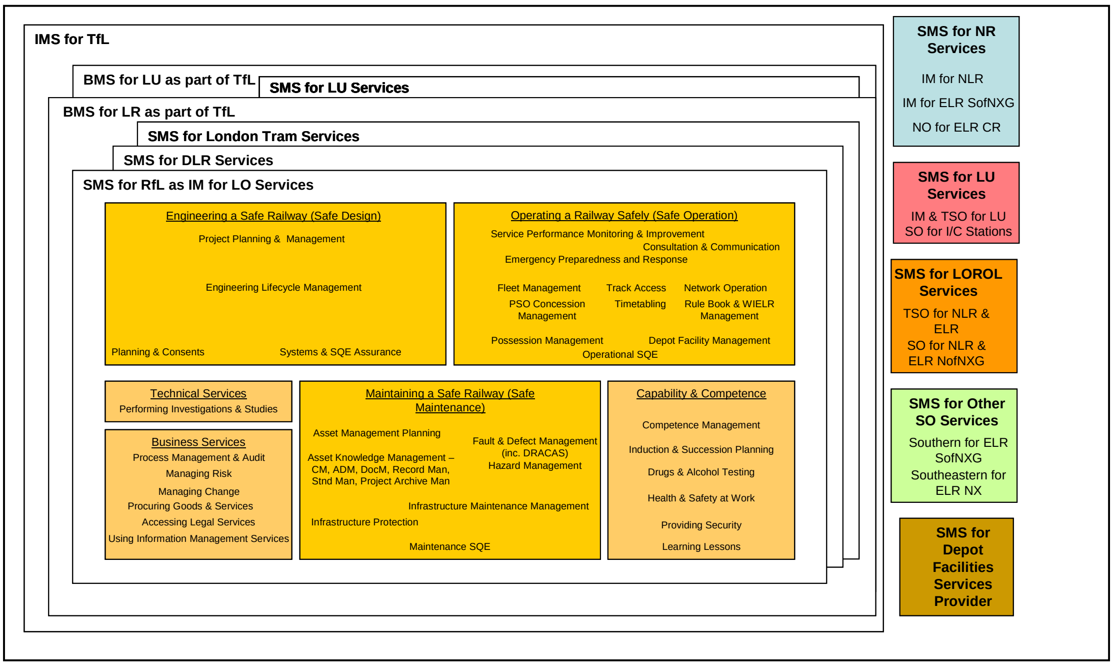

Figure 12 – SMS Functions within the context of other SMS and other TfL Management Systems

The Maintenance Function now has control of the Asset Information and the Railway Build Configuration, RBC. So the Engineering Function can gain ready access to accurate and up-to-date information about the infrastructure to help with the planning and design activities. However, any proposed change to the RBC by the engineering project must be approved and controlled through the Maintenance Function and this could constrain the design and stifle innovation.

Stimulating Innovation

To address this more constrained situation LO has created a separate function to consider the possible future development of the railway systems and to undertake investigations and studies into emerging technologies and solutions. It is this function that conducts the conceptual work, such as modelling and simulations, feasibility studies and solution option selections, which often are a prelude to a Development Project. Such conceptual stages can often take years and even then sometime do not lead to anything.

Keeping this stage separate from the Engineering a Safe Railway (Safe Design) function means it can be managed in a way that is not constrained by too many controls and procedures and thereby provides for a sufficient degree of flexibility to allow innovation to prosper.

Requirements or Design Lead

With an established railway system built and maintained to proven standards there is a limited number of solution options to any requirements for engineering work. Whereas a new railway system solution should be driven by the fundamental requirements, it is sometimes more appropriate for the engineering on an existing railway to move quickly to a design solution and to base the rest of the engineering lifecycle on proving compliance with that design. This is particularly true for civil and structural assets and for infrastructure and control technology which are extensions of existing systems. It may also be true for small projects and for those with a fixed timescale and or budget that has been based on a particular known solution or technology.

Some extensions or modifications are, however, too complex or demand new and innovative technical solutions to overcome existing constraints. These tend to be where requirements based lifecycles are more appropriate. The designer and developer is then responsible for providing the optimum solution to meet the IM’s needs using the techniques and technology available across the industry. Examples of requirements led projects would be the upgrading of an obsolete signalling system to achieve a significantly improved throughput at higher safety margins. It may also be the case for large multi-disciplined projects, such as a complete new branch line, where the work is to undertaken through a single Design & Build contract.

Engineering Lifecycle

An IM will have engineers who are strong in their discipline area, such as Asset Engineers, but will not normally perform large projects completely ‘in-house’. In LOI Preliminary Design services are provided through a Technical Advisor and the Detailed Design and Build undertaken through a Works Contract or Contractors. The LOI Engineering Team will produce and manage the requirements using the proven Requirements & Interface Management System (RIMS) and associated processes (see reference 4) to define and control the Required Railway Build Configuration (RRBC). The LOI Engineers will then review the Preliminary Design work from the Technical Advisor or Contractor(s). The Works Contractors’ Detailed Design, Build and subsequent Integration, Testing and Commissioning will be supervised by the LOI Engineers, assisted by the Technical Advisor as appropriate. Verification and Validation (V&V) activities will be carried out by the responsible party at each stage of the lifecycle.

Each major piece of engineering work is managed as a project so the initial part of the project lifecycle is ‘Planning’ followed by ‘Progress Monitoring and Reporting’ until the project is complete and closed-down.

The Engineering Lifecycle includes stages for RRBC Management, Preliminary Design, Detailed Design, Factory Production, Site Works, Proving and Putting into Service). Figure 13 shows the Engineering Lifecycle for these stages.

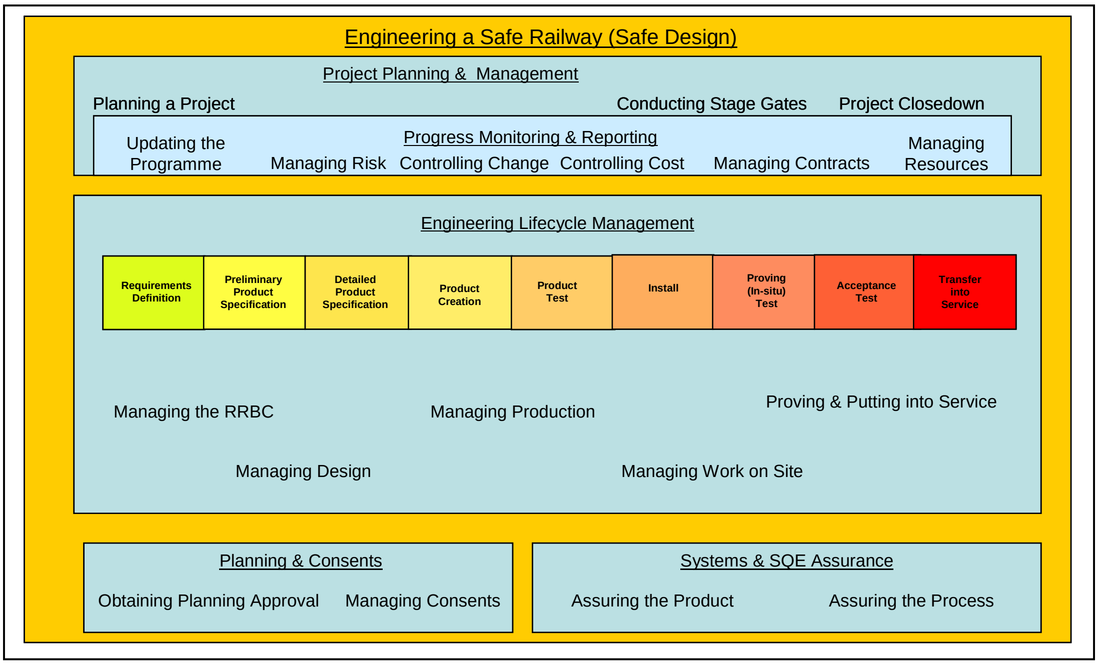

Figure 13 – The Engineering a Safe Railway Function showing the Engineering Lifecycle at its heart.

Assuring the Outcome

It is important that, as we progress through the Engineering Lifecycle, we ensure that evidence is produced to assure all stakeholders that both the Products that are being produced and the Processes being used are as required and in accordance with standards and good industry practice. For this we apply the Progressive Assurance approach developed during the ELLP Phase 1 (see section above). Technical Cases are used to define the Assurance Arguments at all levels of the system breakdown and these are progressively populated with evidence to demonstrate actual progress towards satisfying the arguments. Technical Cases are used throughout the supply chain with the Engineering Team responsible for completion of the highest level Technical Case. Technical Cases are reviewed and approved by representatives of the IM who may employ an independent, competent authority to assist in judging the adequacy for special or complex areas.

The Process argument is represented in a Process, Tools and Competency (PTC) Technical Case (TC) and there will be one for the LOI team and one for each party in the supply chain. The structure of the PTC TC is expected to reflect the Quality Management System of the organisation; making it easy to produce and to verify the evidence through the usual quality audit process.

The Product argument is represented in a TC at each level of system breakdown and completes as the part of the Railway System it represents is satisfactorily integrated with higher level parts. Evidence for the Product TCs generally flows from the V&V activities and is formally collated at each Stage Gate Review.

The structure of TCs has been developed and proven on the ELLP Phase 1 and subsequently further improved to create a number of predefined templates for TC Descriptions, GSN Diagrams and Evidence Tables for use on new projects, hence avoiding ‘reinventing the wheel’. These templates are provided to the supply chain at the start of each contract to make the approach as robust and efficient as possible.

For extension projects where the work on site does not need to disrupt the operational railway there is sufficient time to conduct in-depth inspections and reviews to produce assurance evidence. However for upgrade projects where site work is achieved under limited possessions it is important to make the assurance processes as short as possible and to guarantee to return the railway back into service on time and safely. The balance for how much effort and time is spent during the factory testing stages and the degree of testing on site therefore shifts for different types and scale of project.

Figure 14 shows the Engineering Lifecycle for the stages from when the actual railway build configuration (RBC) starts to become apparent, i.e. at Systems Integration, through acceptance testing on site and then into the proving period for trails operations. It is here that the RBC baseline first appears and is used to compare against the RRBC to determine that what has been built is what was required. The comparison is made at least once at a Stage Gate Review before progressing through to the next stage. The Stage Gate Review Report provides the evidence that the Product has satisfactorily met the requirements at that stage in the lifecycle thus assuring both the LOI project team and IM that we can proceed with confidence.

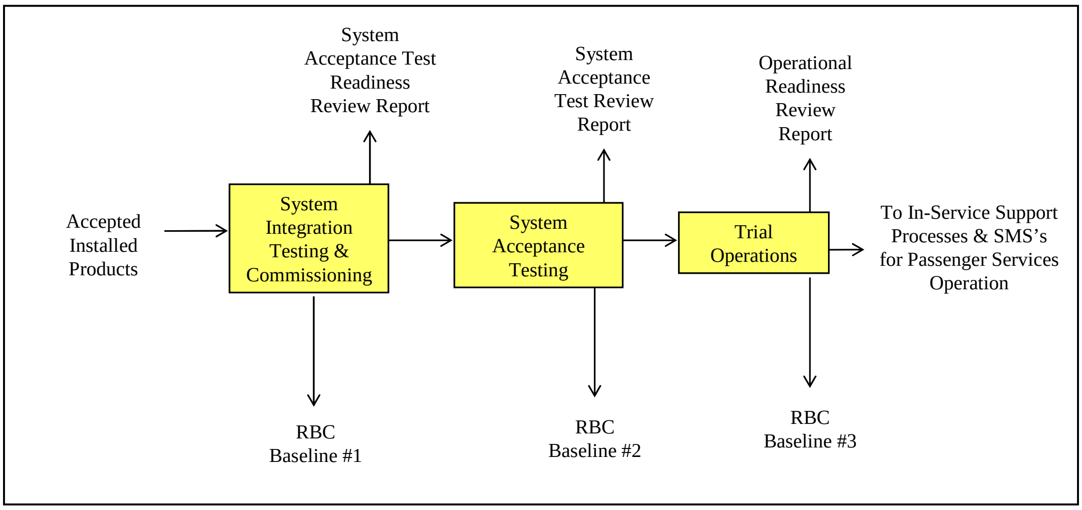

Figure 14 – The Engineering Stages from Systems Integration to transfer into Passenger Operation showing the reports from the Stage Gate Reviews and the RBC Baselines.

Conclusions

Having substantially delivered a complex railway system and having applied some systems engineering practices, in an innovative way, we have learned much. Some of these lessons have been articulated in this paper and many have gone into our preparation to evolve into an IM.

The Engineering Framework we have developed represents our combined attempt to address all the issues we can foresee, to build on the innovative ELLP practices and to adopt industry best practice.

We recognise there will be significant challenges ahead however with the Engineering Framework described herein we, as an organisation, feel ready to face them.

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