Guide

Systems Engineering

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Standard governance

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Document history

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Preface

The Asset Standards Authority (ASA) is an independent unit within Transport for NSW (TfNSW) and is the network design and standards authority for defined NSW transport assets.

The ASA is responsible for developing engineering governance frameworks to support industry delivery in the assurance of design, safety, integrity, construction, and commissioning of transport assets for the whole asset life cycle. In order to achieve this, the ASA effectively discharges obligations as the authority for various technical, process, and planning matters across the asset life cycle.

The ASA collaborates with industry using stakeholder engagement activities to assist in achieving its mission. These activities help align the ASA to broader government expectations of making it clearer, simpler, and more attractive to do business within the NSW transport industry, allowing the supply chain to deliver safe, efficient, and competent transport services.

The ASA develops, maintains, controls, and publishes a suite of standards and other documentation for transport assets of TfNSW. Further, the ASA ensures that these standards are performance-based to create opportunities for innovation and improve access to a broader competitive supply chain.

This guide supports T MU AM 06006 ST Systems Engineering Standard.

This guide has been approved by the ASA Configuration Control Board and is the first issue.
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1. **Introduction**

Transport for NSW and the Asset Standards Authority have adopted a total asset management approach to the planning, acquisition, operation, maintenance and disposal of transport network assets to support the transport services provided to the people of New South Wales. Systems engineering (SE) is the engineering methodology that supports asset management.

The contents of this guide are intended to assist the reader in applying the requirements stated in T MU AM 06006 ST *Systems Engineering*.

This document describes systems and systems engineering (SE). Systems engineering is placed within the context of enterprise management arrangements. The need to define the system overview from different perspectives is identified.

This document also describes the system lifecycle and all stages from both an ISO 15288 standard perspective and the TfNSW asset lifecycle perspective. The need for, and structure of a systems engineering management plan (SEMP) is identified, along with its context to other relevant plans.

Finally the SE general technical processes, specialty processes and related lifecycle processes are identified and explained.

2. **Purpose**

The purpose of this document is to provide guidance on complying with the mandatory requirements of T MU AM 06006 ST *Systems Engineering*.

The benefit of systems engineering as a methodology to project managers in planning and delivering new or altered systems is to mitigate against risks, including poor quality, inadequate performance, cost overrun, schedule overrun and lack of acceptance by the client.

The objective of this SE guide is to develop a structured, repeatable and scalable approach for carrying out SE on transport projects ranging from simple to complex.

The initial objective is to develop this SE guide to support refocusing and revitalising existing transport projects experiencing issues in applying systems engineering and then extend it across the wider transport cluster (for example, Sydney's Rail Future, or Sydney's Ferry Future).

The capability maturity in SE across the spectrum of engineering organisations applying AEO status ranges from very low or emerging awareness, to very high sophisticated application in the transport and other industry sectors. The purpose of this SE guide is to assist low maturity AEOs to better understand the need for, and practical application of SE on projects that may range from simple to complex.

Much of the information, principles and methods in this SE guide may not be new to SE practitioners and AEOs with a high capability maturity in SE application.
2.1. **Scope**

The systems engineering guide sets out the structure and practice for carrying out SE activities on transport projects.

This guide should be read in conjunction with AS/ISO 15288, the *INCOSE Systems Engineering Handbook*, and TS 10504 *AEO Guide to Engineering Management*.

This guide does not cover asset or discipline-specific (for example, signalling, civil, track or electrical) design methods, tools and processes, and is focused at the integrated transport system perspective.

The scope of this SE guide is constrained to, and valid for, public transport systems including heavy rail (passenger and freight), rapid transit metro, and light rail. However, it also facilitates application of SE as a robust engineering methodology to other public transport modes.

2.2. **Application**

SE should be seen as a methodology for engineering complex integrated systems, and not as a separately defined department, discipline or role.

All key stakeholders across the system life cycle should be using or engaging in the SE process, rather than seeing it as the responsibility of a specific project role.

Engineers should understand how to apply SE principles to the appropriate level in a practical and cost-effective manner. This is no different from quality, safety or project management.

The systems engineering guide applies to the following:

- all entities within TfNSW and the supply chain involved in planning, acquiring, operating and disposal of new or altered systems
- portfolio, program and project directors, project managers, systems engineering managers and engineering design managers
- planning and execution of SE activities on TfNSW engineering projects, and across the full system life cycle from concept to disposal
- at a number of levels, including network specific transport mode, line/route, or project

The concepts, principles and processes described in this SE guide should be tailored and scaled to suite the level of novelty, complexity, scale and risk on each project.

Not every element of this SE guide should be applied on every project. Relatively simple track renewal, OHW or minor junction remodelling projects may require a minimal level of application, whereas highly complex, novel network-wide programs may require application of most elements of this guide.
The project-specific engineering management team has the discretion to determine the scale and depth of SE to cost-effectively apply on the project.

3. **Reference documents**

The following standards and documents are either directly referred in this guide or may provide further information and guidance:

**International standards**
- ISO 9001 Quality Management Systems
- AS/NZS ISO 31000 Risk management – Principles and guidelines
- AS/NZS ISO/IEC 15288:2013 Systems and software engineering - System life cycle processes
- ISO/IEC 26702:2007 Systems engineering - Application and management of the systems engineering process
- IEEE 1220:2005, Standard for application and management of the SE Process
- EIA/IS 731.1 Systems Engineering Capability Model
- EN 50126-1:1999 Railway Applications - the Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic Requirements and Generic Process

**Transport for NSW standards**
- T MU MD 00009 ST AEO Authorisation Requirements
- TS 20001: System Safety Standard for New or Altered Assets
- T MU AM 01001 ST Life Cycle Costing
- T MU AM 02001 ST Asset Information Management Standard
- T MU AM 04001 PL TfNSW Configuration Management Plan
- T MU AM 06003 TI Development of a Transport Network Architecture Model
- T MU AM 06004 ST Requirements Schema
- T MU AM 06006 ST Systems Engineering
- T MU AM 06007 GU Guide to Requirements Definition and Analysis
T MU AM 06008 ST Operations Concept Definition
T MU HF 00001 ST Human Factors Integration - General Requirements
T HR HF 00001 ST Human Factors Integration - Rolling Stock
T MU HF 00001 GU AEO Guide to Human Factors Integration

Legislation
Rail Safety National Law

Other reference documents
INCOSE Systems Engineering Handbook, v3.2.2
INCOSE Systems Engineering Body of Knowledge (SEBoK), v1.1
Guide for Application of SE in Large Infrastructure Projects (developed by the INCOSE Infrastructure Working Group)

4. Terms and definitions

The following terms and definitions apply in this document:

ABS asset breakdown structure
AEO Authorised Engineering Organisation
AFC approved for construction
ASA Asset Standards Authority
ATP automatic train protection
BRS business requirements specification
CapEx capital expenditure
CBI computer based interlocking
CED Customer Experience Division (of TfNSW)

complexity refers to the number and type of interfaces between elements of the new or altered system, interfaces with neighbouring systems and environment, number of stages in the migration from present configuration to final configuration, number and type of assets that comprise the integrated system, organisational complexity, and process complexity

CRN Country Rail Network

EMC electromagnetic compatibility
EMI electromagnetic interference

FFBD functional flow block diagram
FRD Freight & Regional Development (of TfNSW)

ICD interface control document

INCOSE International Council on Systems Engineering

IRS interface requirements specification

ISO International Standards Organization

MBSE model based systems engineering

MCD maintenance concept document

novelty refers to systems, assets, processes and support arrangements not used previously on the TfNSW transport network

N-squared chart a diagram in the shape of a matrix, representing functional or physical interfaces between system elements. It is used to systematically identify, define, tabulate, design, and analyse functional and physical interfaces

NWRL North West Rail Link

O&M operator and maintainer

OCD operations concept document

OEM original equipment manufacturer

ONRSR Office of the National Rail Safety Regulator

OpEx operational expenditure

P90 estimate a cost estimate based on a 90% probability that the cost will not be exceeded

PD Planning Division (of TfNS — superseded PPD on 15 April 2015)

PPD Planning & Programs Division (of TfNSW - superseded by PD on 15 April 2015)

project the organisation responsible for planning and delivering new or altered transport systems. The project includes wider portfolio and program organisations.

RAMS reliability, availability, maintainability, safety

RATM requirements allocation and traceability matrix

RIM rail infrastructure manager

risk refers to safety, environmental, political or business risks attributed to introducing the new or altered system

RqDB requirements database

Rqm requirements management

RVTM requirements verification and traceability matrix
SBS system breakdown structure

*scaling* refers to the overall scope and impact of the change, which may be defined in terms of geographical extent, program duration, overall cost, size of the organisation affected, extent of services affected, and the number of operational assets affected

SE systems engineering

SEMP systems engineering management plan

SI systems integration

SIP systems integration plan

SME subject matter expert

SRF Sydney’s Rail Future

SRS system requirements specification

SSRS subsystem requirements specification

*stakeholder* includes the owner, users, customers, operators, maintainers, affected 3rd parties

*system of systems* a collection of task-oriented or dedicated systems that pool their resources and capabilities together to create a new, more complex system which offers more functionality and performance than simply the sum of the constituent systems

TfNSW Transport for New South Wales

TPD Transport Projects Division (of TfNSW – superseded by TPO on 15 April 2015)

TPO Transport Project Delivery Office (of TfNSW – superseded TPD on 15 April 2015)

TSD Transport Services Division (of TfNSW)

V&V verification and validation

*validation* confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

*verification* confirmation, through the provision of objective evidence, that specified requirements have been fulfilled

### 5. Introduction to systems engineering

Systems engineering (SE) is an inter-disciplinary collaborative engineering methodology to derive, evolve and verify a successful transport system solution that satisfies stakeholders’ requirements. It is an iterative problem-solving process, based on the cycle of analyse, synthesise, and evaluate.

SE encompasses individual subsystems and their interactions to form an integrated system to meet stakeholder requirements.
5.1. Systems engineering approach

A system is a combination of hardware, software, people, processes and support arrangements, brought together in a way that satisfies a customer need in the form of a product or service.

SE initially takes ambiguous and complex stakeholder requirements, and applies a structured analytical process to achieve a well-defined and efficient solution.

While introducing a new or altered system into the transport network, the system is defined, analysed, synthesised, verified and validated over its full life cycle up to disposal.

The systems engineering approach is fundamental to bringing high performing fit-for-purpose and cost-effective systems into being.

Systems engineering not only transforms a need into a definitive system configuration for use by its users, but also ensures the system's compatibility and interfaces with related physical and functional requirements. 'Needs' are seen as defining the problem domain, while a 'definitive system configuration' is viewed as the solution domain.

Systems engineering can be applied equally in the problem domain (define the need) as well as in the solution domain (which is the traditional area where systems engineering is applied).

The systems engineering approach considers life cycle outcomes measured by performance, reliability, availability, maintainability, and safety and cost-effectiveness.

The SE methodology considers the whole system life cycle, starting with a 'statement of need', and ending with safe disposal (or renewal) of the system after its intended use.

SE is a process-based engineering approach that flows from concept and requirements, through design, development, installation, testing and commissioning, to operations and maintenance and finally to decommissioning and disposal.

SE is a generic and repeatable approach, which can be applied to any branch of engineering, for both technical product development and infrastructure project delivery.

SE focuses on defining stakeholder needs and functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and functional allocation to subsystems. This is done while considering the complete problem of operations, cost, schedule, performance, training and support, test, manufacturing, and disposal.

5.2. Benefits of systems engineering

Following are some of the reasons why practical use of SE is beneficial:

- SE approach facilitates a clearer understanding of what the client needs
- SE facilitates more efficient design derived from and traced to the client requirements
- SE attempts to ensure that the system functions in an integrated way by removing ‘silos’
• SE considers and provides an approach to minimise or eliminate electromagnetic compatibility (EMC) issues
• SE considers how a reliable, available and maintainable system can be achieved
• SE approach provides justified confidence that the system can be accepted
• SE approach is designed to achieve stated function and performance
• SE approach considers both capital (CapEx) and operational (OpEx) life cycle costs
• successful delivery and acceptance of systems using SE helps release funds for future work

5.3. Possible outcomes of not using systems engineering

A system can fail to meet its intended purposes in many ways and following are some of the outcomes of not using systems engineering:
• uncertainty of client or stakeholder needs, leading to unclear or confusing specification
• excessive redesign, rework, and retesting
• system does not function in an integrated way due to ‘silo’ thinking
• system interferes with or is interfered by others, or has incompatible interfaces
• risk of the system not being accepted (commercial and legal dispute)
• desired system function and performance is not achieved
• system operational and maintenance (OpEx) costs and effort are higher than expected
• system is not operable or usable by staff and customers in a safe, cost-effective manner
• loss of professional and political reputation and the withholding of future funding

5.4. Practical application of systems engineering

Three key SE application scenarios are envisaged for TfNSW projects:
• multi-discipline engineering services on acquisition and implementation projects
• standalone SME consulting service (for example, ReqM, RAM, V&V)
• product development and type approval (relevant to product suppliers)

When planning to apply SE on a project, the following advice is provided:
• combine or scale life cycle phases according to novelty, complexity and risk
• be flexible and pragmatic to ensure that value for money is achieved
• only use SE activities that are relevant to the level of complexity, novelty and risk
• do not over apply SE on every project, scale and tailor it
• SE activities incur time and cost, and this can be detrimental to simple projects
• do not expect all projects to deliver a 'heavy' SE approach
• ensure consistent usage as SE concepts mean different things to different organisations

6. SE context within enterprise management

Systems engineering should be considered as an integral part of overall enterprise management in terms of working with other management methodologies such as asset, risk, project, quality and procurement management of complex systems such as the NSW transport network. SE as a methodology therefore fits within the following broader TfNSW business enterprise context:

• Quality management framework (based on ISO 9001)
• Enterprise asset management framework (based on ISO 55001)
• Enterprise risk management (based on ISO 31000)

SE also relates to other methodologies that support the enterprise level, including the following:

• Project management - SE works in integration with project planning and delivery
• Procurement and supply chain management - SE facilitates clear specification for procuring
• Engineering management (discipline-specific) - SE brings together all disciplines
• Systems and safety assurance - SE provides a robust methodology that supports assurance
• Human resource management - SE considers human as an integral part of the system
• Financial management - SE considers aspects that affect whole of life costs of the system

7. System overview

T MU AM 06006 ST states the following requirement:

"A project shall describe the new or altered system-of-interest, including its high level functions, environment and its functional and physical boundaries and interfaces"

The transport system should be understood and described in order to assist in planning SE activities and assigning roles to a transport project, its environment and functional and physical boundaries.

Figure 1 shows an integrated multi-modal transport system.
The integrated transport system can be considered as a ‘system of systems’, consisting of multiple transport modes such as rail, road, maritime and air transport. Each transport mode as a system in its own right can function more or less independently of the others, with the exception of its interfaces with other modes.

As we focus on a rail transport system, this consists of a number of subsystems, such as rolling stock subsystems, signalling subsystems, telecommunications subsystems, power supply subsystems, and all the civil and structural subsystems. Each of these subsystems do not on their own provide any utility until they are brought together to form the rail transport system that delivers the service. The role of humans as a key part of the system should also be considered.

Further decomposition and inspection of a particular system (for example, rolling stock) identifies that it consists of traction, braking, car body, wheels and bogies, auxiliary power, lighting, door control, train control, heating, ventilation, communications and many other subsystems.

This systematic analysis and decomposition of a system into its constituent elements allows the systems engineer to manage high complexity more effectively.
7.1. **Stakeholder viewpoints**

Any project to introduce new or altered systems with significant levels of novelty, complexity and risk, and therefore requiring a systems approach, has numerous stakeholders.

T MU AM 06006 ST states the following requirement:

"The system description shall describe the system from key user and stakeholder perspectives"

The system should be considered from a number of stakeholder viewpoints, in order to understand how system developers, implementers, users, operators and maintainers will view and interact with the system over its full life cycle from planning to acquisition to operation and maintenance, and finally to disposal.

TS 2001 *System Safety Standard for New or Altered Assets* is available to all stakeholders when considering the system safety from their perspective.

Stakeholder perspectives may include planner, designer, implementer, operator, maintainer and the passenger. This list is not exhaustive and there may be additional stakeholder perspectives. Figure 2 illustrates the multiple viewpoint requirements conceptually.

**Figure 2 - System stakeholder viewpoints**

The planner represents inputs from the following stakeholders:

- Transport Services Division (TSD), the ‘planner and procurer’ of the service provided
- Customer Experience Division (CED), the commuter customer-facing entity
- Freight & Regional Development (FRD), the freight customer service provider
- Operator and Maintainer (for example, Sydney Trains), for delivering timetabled services and maintaining assets
- Planning Division (PD), responsible for the business case and capital budget
- Transport Projects Delivery Office (TPO), for delivery of the acquisition phase of new or altered assets
• Asset Standards Authority (ASA) for potential impact on transport network asset integrity
• Office of the National Rail Safety Regulator (ONRSR), for assurance of network safety
• Other authorities and local government, for interfaces and impacts on own assets

The planner is involved in the ‘concept and specify’ stages of the life cycle (defined in Section 8.3), and views the system with a focus of identifying and analysing service demand, translating this into an operational and maintenance concept, and developing a whole-of-life cycle business case and supporting business requirements.

The planner focuses on TfNSW enterprise goals (that is, the long term transport master plan), supporting operational capabilities, and the concept activities to achieve these capabilities.

The planner also focuses on the system functional, operational and performance requirements.

The designer’s viewpoint is represented by the following:
• Transport Projects Delivery Office (TPO) managing assurance up to approved for construction (AFC)
• operator and maintainer in some cases (for example, for minor capital works)
• design consultancies as AEOs

The designer views the system with an intent to translate the business requirements into a system requirements specification (SRS) and system architecture leading to a reference design. Once the system functional baseline and reference design is established, detailed design starts. During this stage, the system requirements are traced and allocated to subsystems, and the functional baseline is translated into a physical design solution, up to the AFC point.

During the process, the designer considers interfaces, RAM, EMC, human factors and safety. This work is carried out by AEOs under contract generally to TPO or other TfNSW project delivery organisations.

The implementer’s viewpoint is represented by the following:
• Transport Projects Delivery Office (TPO) managing construction, integration and testing, and post-AFC assurance up to system acceptance
• construction and testing companies as AEOs
• operator and maintainer, as RIM/RSO responsible for providing infrastructure access to AEOs

The implementer views the system with an intent to translate the approved for construction design into a built asset, carrying out ongoing verification and validation activities to progressively assure that the realised asset meets the design intent and original client requirements. The implementer works with the designer to plan and execute all systems integration and testing activities.
The operator and maintainer’s (O&M) viewpoint is represented by the transport agencies and contracted O&Ms.

While this guide is developed initially to apply directly to rail transport, the O&M stakeholder viewpoint could extend to include other transport modes such as ferries and buses.

The operator and maintainer views the system from the perspective of ensuring that the original business and system requirements and the evolving system solution is operable and maintainable and sustainable over the systems operational lifetime.

7.2. Requirements hierarchy and structure

Systems engineering determines the following outputs at the early stages of the system life cycle, using a multidisciplinary approach:

- functional, performance, non-functional and interface requirements
- appropriate management process requirements
- production or construction requirements
- sustainable operational and maintenance support requirements
- system disposal requirements

The development of complex integrated systems (or systems of systems) requires a top-down approach to define, allocate and trace requirements. This starts with identifying the enterprise need/goal(s) and supporting capability, then defining the concept activities in an operations concept document (OCD) and maintenance concept document (MCD). These documents then support the development of the business case and associated business requirements specification (BRS).

When the business case and funding request is approved by NSW Treasury and the BRS is issued, the responsibility for developing and delivering the project to provide the new or altered assets passes to Transport Projects Delivery Office (TPO).
TPO establishes a project team of technical advisors (drawn from industry AEOs) to develop the concept design up to a reference design with an associated system requirements specification (SRS), and issues an invitation to tender (ITT).

Some organisations may choose to define management process requirements, and manage the assurance that these process requirements are successfully implemented on the project. The TfNSW requirements schema does not make provision for management process requirements, but some AEOs may be required to manage them as part of overall assurance.

When the tender is awarded, the AEO chooses to either follow the reference design or develop its own design. This involves allocating system requirements from the SRS into subsystem requirements specifications (SSRS) and detailed subsystem designs.

During the course of requirements definition and analysis, inputs are identified and traced back to source documents (policies, strategies, long term plans) and informing documents.

This development of requirements should be captured and traced in a management tool. The selection of the applicable tool is based on complexity as well as contractual requirements.
7.3. **Operational concept definition**

The operational concept definition (OCD) describes how the new or altered system is expected to operate without detailing the technical solution, and is used to inform the BRS and associated business case.

The benefit of an OCD is to mitigate against the risk of not meeting operational requirements. The OCD should not be seen as an optional project overhead but as an integral part of the normal project processes. T MU AM 06006 ST states the following requirement:

"A project shall ensure that a preliminary operational concept definition (OCD) for the new or altered system is prepared early in the system life cycle, before CM gate 1 and to inform and be part of the final business case and business requirements specification"

The project team should summarise the operational concept for the new or altered system and refer to the need for a full operations concept definition (OCD) early in the project or asset life cycle, before the final business case and BRS.

An OCD for every project type may not be produced and the need for one should be scaled and tailored to the scope and complexity of the project. An OCD is produced at a complex multi-project program-level such as a line upgrade or capacity enhancement, and the individual projects within that program fall under that single program-level OCD.

However, there may be situations where relatively small projects require an OCD. The project should consult with relevant stakeholders to determine the need for an OCD.

The OCD should be reviewed and refined as the system definition progresses beyond the BRS and should be finalised when the system solution has been sufficiently defined.

T MU AM 06006 ST states the following requirement:

"The operational concept definition shall describe how the system will be used and operated over its operational lifetime"

The OCD is used to describe the service plan to be delivered and supporting operational organisation, process scenarios, operating modes, and operational facilities to support that plan. The OCD is not a requirement specification, but is written in a manner that explains how the new or altered system is expected to be operated over its design life. This includes any interim operating arrangements as part of a wider operational capability migration.

T MU AM 06006 ST states the following requirement:

"The operational concept definition shall support the business case and associated whole of life funding, which includes how much it will cost to operate over its operational lifetime, as defined in T MU AM 01001 ST"

The business case and its funding request are meaningless without properly considering how the new or altered asset would be operated and how much it would cost to operate.
An understanding of the roles and facilities that are required to support the operational concept scenarios associated with the offered service, allows initial estimates to be made for the operational costs over the system's operational lifetime.

The operational concept definition should be applied and scaled at the appropriate level of novelty and complexity of the proposed new or altered system.

For example, OHW or high voltage aerial feeder projects may not require an OCD; however an OCD may be required at a higher portfolio or program level, for example, for a network-wide power supply upgrade program that consists of multiple feeder, substation and OHW projects.

OCD requirements are defined in T MU AM 06008 ST Operations Concept Definition.

7.4. **Maintenance concept definition**

The maintenance concept definition (MCD) describes how the new or altered system is expected to be maintained without detailing the technical solution, and is used to inform the BRS and associated business case.

T MU AM 06006 ST states the following requirement:

"A project shall ensure that a maintenance concept definition (MCD) for the new or altered system is prepared early in the system life cycle, before CM gate 1 and to inform and be part of the final business case and business requirements specification"

An MCD for every project type may not be produced, and the need for one should be scaled and tailored to the scope and complexity of the project.

MCD is produced at a complex multi-project program level such as a line upgrade or capacity enhancement, and the individual projects within that program falls under that single program-level MCD.

However, there may be situations where even relatively small projects require an MCD. The project should consult with relevant stakeholders to determine the need for an MCD.

T MU AM 06006 ST states the following requirement:

"The maintenance concept definition shall describe how the system will be maintained over its lifetime"

The maintenance approach has a significant impact on cost, time, resources and overall asset condition over its expected lifetime.

The blend of planned and unplanned maintenance should be estimated, based on the selected approach. This may include adopting a condition-based maintenance approach, where significant capital cost is expended in providing remote condition monitoring of assets. This may result in better prediction of potential failures, and may lead to reduced response times, lower mean time to repair, and higher system availability.
T MU AM 06006 GU Systems Engineering Version 1.0
Issued date: 05 May 2015

T MU AM 06006 ST states the following requirement:

“The maintenance concept definition shall support the business case and associated funding, which includes how much it costs to maintain and support over its operational lifetime”

The business case and its funding request are meaningless without properly considering how the new or altered asset would be maintained and how much it would cost to maintain and support over its full operational life (OpEx). The business case should be based on a discounted cash flow model, beginning with accumulated capital costs, followed by predicted maintenance expenditure, estimated revenue (ticket box and funding subsidy), and asset depreciation over the full design asset lifetime until disposal.

T MU AM 06006 ST states the following requirement:

"Maintenance concepts defined in the maintenance concept definition shall align with, and support, operational concepts defined in the operational concept definition"

In some cases, the OCD and MCD may be combined into a single document. Since the entity responsible for operating the system is usually the maintainer of the system, the operations and maintenance concepts can be combined where practicable, as they are closely related.

For example, the policy for accessing the system for maintenance purposes should consider the impacts on the operational service and associated service performance measures. This may be articulated in the yearly possession plan (for implementing new or altered systems and planned maintenance), which is developed in collaboration with the transport operator to ensure that suitable special arrangements are in place to minimise service disruption.

Another example may be a business decision to move to a service that increases passenger service hours over a 24 hour period, effectively reducing maintenance windows, in which case alternative system maintenance and access arrangements need to be articulated in the MCD.

### 7.5. Functional architecture

T MU AM 06006 ST states the following requirement:

"A project shall describe the functions for the new or altered system and how these relate to operational concept activities, operational capabilities and high-level TfNSW goals"

The project should describe the hierarchy of functions for the new or altered system, and how it relates back to concept activities, capabilities and enterprise goals. The project should also describe if required, the system in terms of functional flow block diagrams (FFBD) with functions decomposed until all functions are purely system performed functions.

While a functional architecture may be structured around physical asset groups, it is not necessarily the case. Where practicable, the functional architecture should avoid being tightly linked to physical systems and assets. The reason for this is that functions allocated to physical
assets using old or current technology, may in future be allocated to other physical assets that can provide superior functionality and performance.

De-linking of functions from physical asset groups permits innovative solutions to be offered by existing and new product suppliers.

An example of this is the current issuing of a ‘movement authority’ via existing trackside colour light signals. This changes to an ETCS-L2 ‘electronic movement authority’ issued via a radio block centre and GSM-R radio network directly to the onboard train control system.

This does not imply that suppliers are able to offer an innovative solution for every project. In many cases from a logistic support perspective it is not practical to have a large range of novel and diverse solutions and assets to maintain. Standard solutions using type approved products in proven standard configurations may still be more desirable in many cases.

Projects using established type approved products in standard configurations, and heavy civil engineering assets may not need to develop a functional architecture, as it mostly benefits high-complexity, high-integrity command, control and communications systems.

In order to develop a functional architecture, a standard reference architectural framework should be adopted that ensures a common approach and syntax to defining the functions.

The TRAK metamodel developed by RSSB (UK), and adopted by the ASA as a core element of its model based systems engineering (MBSE) approach, is used as a reference guide. This forms the basis of the transport network functional architecture model.

Figure 4 shows an example of a functional architecture sample fragment using TRAK.
7.6. **Physical solution architecture**

T MU AM 06006 ST states the following requirement:

"A project shall describe the physical system breakdown structure (SBS) of the proposed new or altered system, and describe how the physical solution will be configured"

In some cases, the use of the term asset breakdown structure (ABS) is used in documents and projects in TfNSW to mean SBS. For the purpose of this guide and T MU AM 06006 ST Systems Engineering it supports, these terms are interchangeable.

The SBS is essential for all project types and engineering disciplines in order to identify assets, associated asset data and configuration information to pass from designer to builder to tester to operator and maintainer. The purpose of a SBS is to decompose the system into system elements and interfaces as part of the system design. Figure 5 shows an example of a physical SBS fragment.
T MU AM 06006 ST states the following requirement:

“Physical system block diagrams shall be used to describe the configuration and integration of the physical assets and systems in relation to each other and to their environment”

Physical system block diagrams are usually produced after the functional architecture and SBS are defined and during the process of allocating functions to physical systems or assets.

Physical system block diagrams are usually produced for the electrical, command, control and communications systems, but may not be appropriate or necessary for civil and track systems.

Each block in the system block diagram has one or more functions allocated to a physical system element. For example, in a substation block diagram, there may be block items for the HV incoming panel, HV protection, rectifier-transformer, outgoing dc traction panel, dc protection, SCADA RTUs, lighting and auxiliary power. These would be shown in an integrated physical solution in a drawing.

Figure 6 shows a sample fragment of a physical system block diagram for a portion of a rapid transit railway communications based train control (CBTC) system:
Practical railway examples of physical architectures include the following:

- **signalling**
  - computer based interlocking block diagrams
  - control centre systems diagrams
  - signalling equipment room layouts

- **telecommunications**
  - optical fibre transmission backbone block diagrams
  - communications equipment room layouts, showing SDH, ATM or MPLS units

- **electrical**
  - earth system block diagram, showing key equipment
  - SCADA system block diagram, showing workstations, servers and RTUs

- **track**
  - turnout sketch
  - initial 30% (concept) design for a bridge

- **buildings**
  - building architecture drawing or CAD 3D model, without services details

### 7.7. Geographic deployment architecture

T MU AM 06006 ST states the following requirement:

"A geographic architecture shall be used to describe where the physical assets will be deployed on the TfNSW transport network"

The geographic deployment architecture diagram facilitates design by positioning the physical assets at a geographic location, and allows construction and maintenance organisations to identify logistic support and incident response times.

Figure 7 shows a sample fragment of a geographical architecture diagram for a rapid transit railway.
Figure 7 - Geographic architecture diagram (sample fragment)

Practical railway examples of geographic architectures that indicate the geographic layout and disposition of physical assets and systems include the following:

- geospatial (GIS) models of the transport corridor, assets and facilities
- signalling
  - signalling plans, locating signalling assets along the rail corridor
  - track insulation plans, locating insulation and bonding to OHWS in the corridor
  - cable route plan: locating cable routes, joint pits and cable crossings
  - level crossing layout plans: locating signals, traffic lights, road signs
  - drivers diagrams: locating signals, points, indicators, signage, radio channels
- telecommunications
  - telecommunication cable route plans
- electrical
  - high voltage feeder routes
  - high voltage operating diagrams
  - substation layout drawings
  - HV/traction switching diagrams
- track
  - depot and stabling yard layout plans
  - track plans
  - level crossing plans
7.8. System context and interfaces description

T MU AM 06006 ST states the following requirement:

“The new or altered system shall be described in terms of its context to existing systems, and to its operational environment”

Entity-relationship diagrams can be used to define interfaces and interactions between systems.

Figure 8 shows a sample fragment of a system context diagram:

![System context/interface diagram (sample fragment)](image)

These diagrams can be augmented by N-squared charts, which facilitate planning and specification of system interfaces in detail via interface control documents (ICDs) and interface requirements specifications (IRS), depending on level of complexity. An example of an N-squared chart in the form of an interface control document (ICD) matrix is shown in Appendix F.
7.9. **Interim system migration states**

On high-complexity programs and portfolios of projects such as automatic train protection (ATP), power supply upgrade (PSU), fleet replacement or Sydney's Rail Future (SRF), commissioning the entire new or altered system into operation in one stage may not be possible.

Interim configuration states and migration from one configuration state to the next should be identified, planned and scheduled. This may include interim pre-testing of systems in an 'over and back' arrangement, and then leaving them dormant (that is not commissioned into full operation) to await readiness of other related systems for system integration at a later date.

These interim configuration states should be identified and described as part of the architectural diagram viewpoints as described in Section 7.5, Section 7.6 and Section 7.7.

8. **System life cycle description**

T MU AM 06006 ST states the following requirement:

“A project shall deploy a ‘whole of life’ systems engineering approach to the planning and acquisition of the new or altered system”

Most systems engineers and project managers are familiar with the traditional V-model of the system life cycle defined in ISO15288, and the *INCOSE SE Handbook*. This model maps a vertical scale of increasing system definition (system, subsystem, and unit) against a horizontal timescale of system life cycle phases from exploratory phase (need identification and pre-feasibility) through to retirement phase (disposal). Figure 9 shows the TfNSW system life cycle V-model.
The V-model is aligned to the asset management life cycle stages defined in the key TfNSW Configuration Management and Asset Assurance Committee (CMAAC) gateways.

However, the V-model is a highly simplified perspective of the real world. The planning, design, implementation, operation and management of high complexity and novelty transport systems is characterised by a number of V-models over the full system life cycle, as shown in Figure 11.
8.1. Integrated system life cycle

The multiple system life cycle is viewed from the specific application and generic product perspective and is elaborated more in detail in C.2 of Appendix C.

This expansion of the V-model may take many forms and depends on the nature of the project.

The generic system application life cycle applies to pilot or trial projects run by TfNSW entities to develop a proof-of-concept and standard generic approach to application of new technology at a system level (for example, initial ETCS-L1 trial on Blue Mountains Line and later ETCS-L2 trial).

The specific system application life cycle applies to specific system implementation projects planned by Planning Division (PD), delivered under contracts usually managed by Transport Projects Delivery Office (TPO).

The system support life cycle applies to mid-life upgrades by the operations and maintenance entity to address mid-life performance, reliability or safety issues. These are considered as ‘mini projects’ such as track renewal or refurbishment, sectioning hut relocation or track slewing to enhance line speed, but do not involve new or altered assets.

The generic product development (supplier) life cycle applies to original products developed by suppliers, from product inception to release and generic acceptance. An example could be a computer based interlocking (CBI) product developed by an OEM supplier for use by multiple client organisations on their transport network (possibly with client-specified adaptations).
The generic product adaptation (supplier) life cycle applies to generic products developed by the OEM suppliers that require some adaptation to meet specific client organisation application requirements. An example could be the adaptation of interlocking data constructs and software rules in a computer based interlocking to suit signalling principles of a local railway operator. The OEM supplier is responsible for managing generic product adaptation with TfNSW input.

The generic product support (supplier) life cycle applies to original products developed by OEM suppliers, adapted for specific applications, and installed on the client network, that require ongoing OEM logistic support in terms of mid-life software upgrades or hardware modifications.

Further complexity is introduced into the practical application of the V-life cycle model when planning and acquiring complex transport systems. However, not all subsystem development starts at the same time, as shown in C.2 of Appendix C.

8.2. Scaling and tailoring SE effort

T MU AM 06006 ST states the following requirement:

"The level of systems engineering shall be scaled and tailored according to an assessment of the novelty, scale, complexity and risk associated with introducing the new or altered system"

When planning the acquisition and implementation of a new or altered system for the wider transport network, a practical level of systems engineering should be determined to be applied to the change.

Excessive SE effort may be inappropriate for the level of novelty and complexity to be managed. This may result in excessive engineering cost and poor value for money. Similarly, insufficient SE effort may result in a system delivered that fails to meet strategic objectives, business needs and operational requirements, resulting in poor whole of life performance.

Guidance on appropriate scaling and tailoring of SE effort to address novelty, complexity, scale and risk is provided in the project example table in Appendix B.

8.3. System life cycle stages

The INCOSE Systems Engineering Handbook defines a number of life cycle stages that a system passes through, which broadly align with the TfNSW asset life cycle. These stages are interpreted in Section 8.3.1 through to Section 8.3.7.

8.3.1. Exploratory stage

This stage maps to the plan stage (need and concept) in the TfNSW asset lifecycle.

T MU AM 06006 ST states the following requirement:

"Safety responsibilities of all parties at this stage shall be in accordance with the TfNSW safety management system (SMS) and TS 20001 System Safety Standard for New or Altered Assets"
Key responsible parties include CED, TSD, FRD and PD. The operator and maintainer or Rail Infrastructure Manager (RIM) may also be involved in this stage and all other life cycle stages as part of due diligence accountability under Rail Safety National Law.

Key activities and deliverables include transport demand or needs analysis, development of multiple service options, and an early concept of operations (ConOps) definition.

### 8.3.2. Concept stage

This stage maps to the plan stage (feasibility and procure) in the TfNSW asset life cycle.

Key responsible parties include CED, TSD, FRD and PD, and also involve the O&M.

Key activities and deliverables include high-level transport performance modelling to validate the early operational concept definition (OCD) and maintenance concept definition (MCD) development, preferred option concept design, preliminary business case, risk-assessed cost estimate and the BRS.

### 8.3.3. Development stage

This stage maps to the plan stage (feasibility and procurement) in the TfNSW asset lifecycle.

Key responsible parties include PD and TPO (project development) with AEO support.

Key activities and deliverables include detailed transport modelling, OCD and MCD refinement, SRS and reference design development, P90 risk-assessed cost estimate, final business case, and tender documentation.

### 8.3.4. Production stage

This stage maps to the acquire stage (design, build, integrate, and accept) in the TfNSW asset life cycle.

Key responsible parties include TPO (project delivery) and industry supply chain AEOs, and may involve the O&M and certain capital investment projects.

Key activities and deliverables include development of detailed designs, bills of materials and product specifications, procuring or fabricating products or equipment, installation or construction and integration on site, subsystem and system testing, commissioning and handover to the TfNSW asset owner and O&M.

### 8.3.5. Utilization stage

This stage maps to the operate and maintain stage of the TfNSW asset life cycle.

Key responsible parties include the transport agencies, contracted O&Ms and other transport operators.
Key activities and deliverables include asset acceptance from the project delivery organisation, ongoing operation of these assets, and periodic major maintenance or minor capital projects to restore system performance capability to the original design intent.

### 8.3.6. Support stage

This stage maps to operate and maintain stage of the TfNSW asset life cycle, and runs concurrently with the utilisation stage.

Key responsible parties include the transport agencies or contracted asset management AEOs and AEO product suppliers.

Key activities and deliverables include asset acceptance from the project delivery organisation, asset condition assessments, preparing asset maintenance plans, carrying out general asset maintenance and support activities (including mid-life upgrades) against these plans.

### 8.3.7. Retirement stage

This stage maps to the dispose stage of the TfNSW asset life cycle.

Key stakeholders include the transport agencies and other contracted asset management and operations organisations who may be AEOs, making the decision as to when an asset should be retired from operational service.

Key activities and deliverables include asset condition assessments to support any decisions to retire systems.

### 9. Systems engineering organisation structure

T MU AM 06006 ST states the following requirement:

"A project shall define its organisational management structures for systems engineering"

A matrix organisational structure divides authority both by functional area and delivery work stream. In a matrix structure, each team member reports to two immediate managers, that is, a functional lead (technical SME) and a delivery lead (manager); Figure 12 shows sample fragment of typical matrix-based railway project delivery organisation.
The functional leads are charged with overseeing staff in a functional specialist area such as an engineering discipline (civil, track, signalling) or SE role (requirements, RAMS, V&V).

The delivery leads manage specific and time-constrained work packages within each project. They draw engineering staff from various technical SME functional areas to deliver their specific work packages within the project.

Following are some of the advantages of matrix organisational structure:

- resource coordination (leads focus on area of expertise, either engineering or PM)
- specialisation (staff focus on applying their specific domain knowledge to the project)
- breadth of skill
- communication (not more than two layers of communication to the executive)
- flexibility of the team to redeploy resources

The sample structure in Figure 12 is for a large project or program, where each function or activity requires a uniquely defined management role. For smaller projects, staff may have

**Figure 12 - Matrix project organisation (sample fragment)**

The functional leads are charged with overseeing staff in a functional specialist area such as an engineering discipline (civil, track, signalling) or SE role (requirements, RAMS, V&V).

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- breadth of skill
- communication (not more than two layers of communication to the executive)
- flexibility of the team to redeploy resources

The sample structure in Figure 12 is for a large project or program, where each function or activity requires a uniquely defined management role. For smaller projects, staff may have
multiple roles and the layers of project management would be reduced. Scaling and tailoring of SE effort is essential.

9.1. Systems engineering roles and responsibilities

T MU AM 06006 ST states the following requirement:

"A project shall define its systems engineering roles and responsibilities"

In any organisation, the entity responsible for the delivery of SE services to support the acquisition and implementation of new or altered systems should ensure that all SE roles and associated responsibilities are clearly defined.

In many cases a single role may be assigned with more than one SE responsibility where scaling and tailoring of SE effort is appropriate on simpler projects.

SE organisation roles and responsibilities should not duplicate or conflict with other management areas of the overall organisation; for example, project management, procurement, risk, system safety assurance and others.

For simple projects the SE effort may be carried out by the design team or principal contractor. A SE organisation with dedicated role descriptions is not always necessary (for example, SE manager, requirements manager, interface manager, and so on.), as long as the appropriate level of SE is carried out competently by the organisation.

For example in some simpler projects, elements of SE effort could be carried out by the design manager or engineering manager. For very simple projects, the project manager, engineering manager and design manager roles may be combined and some basic SE effort may be carried out by the consolidated role.

T MU AM 06006 ST states the following requirement:

"Levels of responsibility and engagement of systems engineering organisational roles shall be mapped to systems engineering management processes and activities across the system life cycle and communicated to staff"

Table 1 identifies key SE management roles in an organisation that deals with high levels of novelty, complexity and risk in the planning and acquisition of new or altered systems. It assigns key responsibilities to each role on the basis of a complex project.

This does not imply that all the SE roles and responsibilities are required for every project. For simple projects using type approved products in standard configurations, for example OHW or track renewal or upgrade projects, an SE manager, is not practical.

Similarly, for extremely complex and novel systems (for example, ETCS-L2), SE responsibilities listed in Table 1 may represent the minimum SE roles and responsibilities.
<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| Systems engineering manager  | • identify SE management requirements, effort and work breakdown structure (WBS)  
|                               | • identify SE resources required to support SE activities appropriate to the project phase  
|                               | • assign clear responsibilities and accountabilities to SE team members  
|                               | • support project manager (PM) to implement effective controls and measures in delivery of engineering outputs throughout the project life cycle by tailoring the SE principles  
|                               | • support design and engineering functions to control and assess the health and maturity of the engineering outputs throughout the project life cycle  
|                               | • ensure technical reviews to enable progressive assurance are included in scope of works between TfNSW and third parties delivering services and products  
|                               | • ensure systems interface management and coordination activities between project work streams are implemented, and results documented and distributed  
|                               | • review contractor submissions for compliance with SE requirements  
|                               | • identify and report on compliance gaps against SE practices adopted on the project                                                                                                                                 |
| Requirements manager          | • identify stakeholders and the level of requirements management needed on the project  
|                               | • develop a requirements management (RqM) plan to support the requirements engineering, including activities in support of safety and human factors integration  
|                               | • identify, select, implement and maintain an appropriate RqM tool  
|                               | • plan, organise and facilitate requirements definition workshops with relevant and authorised project stakeholders to obtain input to the requirements definition  
|                               | • elicit requirements, configure, compile and update the requirements database (RqDB) to support establishing requirements baselines in alignment with major project phases  
|                               | • compile requirements specifications with SE team members and stakeholders  
|                               | • produce baseline requirements specifications (BRS, SRS, SSRS, IRS)  
|                               | • monitor and report on requirements allocation and traceability  
|                               | • communicate and coordinate activities with other SE management activities                                                                                                                                 |
| Systems integration manager   | • identify systems integration (including migration and interim configuration) requirements  
|                               | • establish and maintain a systems integration plan (SIP) as required  
|                               | • identify, implement and use systems integration (SI) tools as required  
|                               | • execute SI tasks and activities related to the engineering effort  
|                               | • communicate and coordinate SI activities with other SE management activities                                                                                                                                 |
| Systems architecture manager  | • identify systems architecture models and viewpoints to suit project scope and complexity  
|                               | • establish and maintain a systems architecture management plan as required  
|                               | • identify, implement and use systems architecture tools as required  
|                               | • execute systems architecture management tasks and activities related to the effort  
<p>|                               | • communicate and coordinate activities with other SE management activities                                                                                                                                 |</p>
<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| Systems interface manager  | • identify systems interface requirements, and capture these in the RqDB  
• establish and manage a system interface plan (SIP) as required  
• identify interface hazards and risks as part of the overall safety assurance activities  
• prepare interface control documents (ICDs) and interface requirements specs (IRSSs)  
• establish and maintain a systems interface management plan or schedule as required  
• identify, implement and use systems interface tools as required  
• execute systems interface management tasks and activities related to the effort  
• communicate and coordinate activities with other SE management activities |
| V&V manager                 | • identify V&V requirements, including V&V methods, criteria, responsibility and status  
• establish and maintain a V&V Management plan as required  
• identify, implement and use V&V tools as required  
• execute V&V tasks and activities related to the engineering effort  
• communicate and coordinate activities with other SE management activities |
| RAM manager or engineer     | • identify RAM modelling and analysis requirements  
• establish and maintain a RAM management plan as required  
• identify, implement and use RAM tools as required  
• execute RAM tasks and activities related to the engineering effort  
• assist the system safety manager in compiling and updating of hazard logs, safety risk registers, fault schedules, and FMECAs  
• communicate and coordinate activities with other SE management activities |
| Human factors integration manager | • identify HF and ergonomic analysis requirements  
• establish and maintain a human factors integration plan (HFIP) as required  
• identify, implement and use HF tools as required to support HF analysis  
• execute HF tasks and activities related to the engineering effort  
• establish an HF project oversight role in addition to third party resources assigned in fulfilment of HF objectives and activities identified in the HFIP  
• communicate and coordinate activities with other SE management activities |
| EMC engineer                | • identify potential EMC threats and EMC modelling and analysis requirements  
• establish and maintain an EMC management plan as required  
• identify, implement and use EMC modelling and testing tools as required  
• execute EMC management tasks and activities related to the engineering effort  
• assist the system safety manager in compiling and updating of hazard logs, safety risk registers with EMC-related hazards  
• communicate and coordinate EMC activities with other SE management activities |
| Configuration manager      | • identify configuration management requirements, including configuration item lists  
• establish and maintain a configuration management plan as required  
• identify, implement and use configuration management tools as required  
• execute configuration management tasks and activities related to the engineering effort  
• communicate and coordinate configuration management activities with other SE activities |
9.2. Project organisation types

Project organisations are scaled and structured according to the scope, scale and complexity of the system (or system or systems) to be delivered. Application of this SE guide needs to be scaled and tailored in its application to suit the following organisations:

- Portfolio management organisations are structured to provide a wide portfolio of programs, which in turn each may consist of multiple projects. Examples of this include portfolio alliance organisations such as Sydney's Rail Future (SRF) Program.
- Program integration management organisations include the ATP, PSU and DTRS programs, which each consist of multiple projects to deliver specific subsystems or geographic scopes.
- Product development organisations include original equipment manufacturers (OEM) that provide generic products that are approved, selected and procured for specific application.
- Project development organisations include PD, Sydney Trains (to some extent) and the project development unit of TPO, who develop projects to the point where an SRS and a costed reference design are issued to tender.
- Project delivery organisations include TPO and supply chain AEOs who deliver the scope of works in terms of detailed designs, procurement, manufacturing/fabricating, installation, integration, testing, commissioning, acceptance and hand over to the asset operator.
- Operations and maintenance organisations include the transport agencies and contracted O&Ms. They plan, execute and measure asset maintenance of TfNSW assets, and these may take the form of a renewal or replacement or refurbishment project.

9.3. RACI Matrix

Levels of responsibility and engagement of key organisational roles should be mapped to SE and related processes in a RACI matrix, and communicated to all staff. While the RACI is not the only way to easily identify and communicate responsibility, it is the most commonly used and understood method.

The partially completed example of a RACI matrix in Figure 13 broadly represents a project engineering organisation and the associated responsibilities for a high complexity, high novelty program of works.
10. Systems engineering shared information

T MU AM 06006 ST states the following requirement:

"Systems engineering related shared information resources shall be mapped to system life cycle processes, and identify which information resource is owned or used by which process owners"

Over the system life cycle, during planning and acquisition phases, a significant body of information is generated by different technical and related processes and activities. Much of this information is shared by multiple processes in arriving at an integrated solution that meets the user requirements.

A good practice is to assign ownership of information to one process owner, and then to identify which other processes use that shared information.

T MU AM 06006 ST states the following requirement:

"Records shall be kept of implementation of SE processes, including traceability to competence of staff managing and using those processes"
Records of due process followed by all members of the organisation who are responsible for delivering the new or altered system are essential to provide assurance that all claims for performance and safety of the system are traceable and supported by objective, verifiable evidence.

A key element of the overall safety assurance claim is based on the delivery of the new or altered system by competent persons.

The level of competence required to assure the system depends on the nature of the change. A simple at-grade car park project outside the rail corridor clearly has a lower requirement for the level of detailed information and records required for the assurance argument, than a project to introduce a novel train control system. This requires tailoring and scaling to provide a pragmatic approach to the level of complexity, novelty and risk.

Figure 14 illustrates this ownership and usage of shared technical information.

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**Figure 14 - Shared information resources and SE related processes**

<table>
<thead>
<tr>
<th>SHARED INFORMATION</th>
<th>SYSTEMS ENGINEERING &amp; RELATED PROCESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Source Baseline</td>
<td>O U U U U U U U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Standards Baseline</td>
<td>O U U U U U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Requirements Database</td>
<td>U U U U U U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Functional Architecture</td>
<td>U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Physical Architecture</td>
<td>O U U U U U U U</td>
</tr>
<tr>
<td>Bill of Materials (BOM)</td>
<td>O U</td>
</tr>
<tr>
<td>Engineering Change Register</td>
<td>U U U U U U U U U U</td>
</tr>
<tr>
<td>Configuration Database</td>
<td>U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Design Models/Information Register</td>
<td>U U O O O O O O U U U U U</td>
</tr>
<tr>
<td>Document/Data Register</td>
<td>U U</td>
</tr>
<tr>
<td>EMC Threat Matrix/Risk Register</td>
<td>U U</td>
</tr>
<tr>
<td>Engineering Comments Register</td>
<td>O U U U U U</td>
</tr>
<tr>
<td>Verification Error Log</td>
<td>O U U U U</td>
</tr>
<tr>
<td>Hazard Log/Safety Risk Register</td>
<td>U U U U U U U U</td>
</tr>
<tr>
<td>Systems Integration Schedule</td>
<td>O U</td>
</tr>
<tr>
<td>Technical Interface Register</td>
<td>U U U U U U U</td>
</tr>
<tr>
<td>Interface Control Docs</td>
<td>U U</td>
</tr>
<tr>
<td>Technical Issues Register</td>
<td>U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Technical Maintenance Plans</td>
<td>O U U</td>
</tr>
<tr>
<td>Manufacturing Database</td>
<td>O U</td>
</tr>
<tr>
<td>Non-Compliance Register (audit)</td>
<td>U U U U U U U U U U U U U U U U U</td>
</tr>
<tr>
<td>Roles/Responsibilities Chart</td>
<td>U U</td>
</tr>
<tr>
<td>System RAM Models (RBD)</td>
<td>U U U U</td>
</tr>
<tr>
<td>System Safety Models (FTA, GSN)</td>
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11. Systems engineering management plan

T MU AM 06006 ST states the following requirement:

"Where an assurance argument based on a judgment of significance (JOS) identifies the need for a systems engineering management plan (SEMP), this shall be produced"

The need for a standalone systems engineering management plan (SEMP) depends on the level of scope, novelty, complexity and risk associated with the acquisition of new or altered assets.

11.1. Identify the need for systems engineering management plan

A SEMP should not be developed for each type of project, and should only be produced where the level of SE is expected to be considerable, and requiring dedicated resources.

In the case of a large collection of similar, relatively simple projects, executed under a common program of works (for example, station easy access projects under the Transport Access Program), then a single program-level SEMP may be sufficient to address all SE activities across the program.

T MU AM 06006 ST states the following requirement:

"Where the need for an SEMP cannot be justified, the appropriate scale of systems engineering activities shall be identified in the engineering management plan or project management plan"

For simple projects using type approved products in standard configurations, the need for heavy application of SE and detailed standalone SEMP may not be justifiable. In such cases, SE may be applied lightly and describe the SE activities within the project engineering management plan, project delivery plan, or equivalent management plan.

For example, a project whose scope involves the delivery of an at-grade car park, overhead wiring or a high voltage aerial feeder to a substation may not require significant SE effort, other than the briefest of requirements, some interface management, qualitative RAM analysis, and some qualitative EMC analysis based on compliance to established standards. This could be embedded in a standard project delivery plan or engineering plan, and would not require a dedicated SEMP.

11.2. SEMP and concept phase

T MU AM 06006 ST states the following requirement:

"The SEMP shall ensure that all system engineering management objectives are achieved. The SEMP shall be prepared during the concept phase"
Due to the nature of SE as a whole-of-life approach to the delivery of systems, the planning of SE activities and deliverables should begin as early as possible, particularly in the concept phase. This allows for early definition and analysis of business requirements and how they translate into system requirements.

The SEMP should define the system level objectives to be achieved, such as increase line capacity from 20 trains per hour to 24 trains per hour, increase traction current in feeder sections from 5000 to 6000 Amps, or increase passenger capacity in station concourse from 1000 to 2000.

11.3. Systems engineering deliverables

T MU AM 06006 ST states the following requirement:

"The SEMP shall define the SE deliverables to be completed prior to each gateway"

Gateway requirements defined by CMAAC gates 0 to 6 and subordinate CCB gateway requirements at the project delivery level define the required deliverables. For example, CMAAC gate 1 deliverables may include (but are not limited to) the following:

- business requirements specification complete and signed by sponsor
- operational concept complete and signed by sponsor
- maintenance concept complete and signed by sponsor
- initial safety change plan established and signed by sponsor

11.4. SEMP content

T MU AM 06006 ST states the following requirement:

"Where a SEMP is required, it shall include the following sections as a minimum:

- objective or need
- document context and document relationship tree diagram
- system requirements structure
- system scope and boundary description
- system interfaces
- system life cycle and stage gates description
- systems engineering technical processes
- systems engineering organisation, roles and responsibilities
- systems engineering shared information matrix"
The objective or need for a change in transport functional or performance capability forms the basis for the business and system requirements, which in turn form the basis for procuring or building the system. Without clear articulation of the top-level objective or need, a solution that is proposed and developed may not support the need, and may lead to excessive and unplanned whole-of-life costs.

The SEMP as one of a suite of related documents needs to be placed within the context of and related to the other plans that form part of the management arrangements for the change. SE as an engineering methodology cannot be carried out in isolation of project management, safety assurance, risk management and procurement management plans.

The requirements structure should clearly articulate how top-level business objectives and needs are translated into operational and service level requirements, and finally into system level requirements that define the solution to be acquired.

The requirements structure should indicate traceability of requirements, and how they are verified and validated.

Allocation of system requirements to subsystems should be identified and controlled.

Relationships to documents such as transport plans, regulations and standards should be shown.

The scope and boundary of the system is essential to ensure that the level of SE is scaled and tailored accordingly to ensure value for money and an appropriate level of assurance.

The transport system is highly complex, with many physical, functional and operational interfaces to consider, especially where the system is to be delivered as a series of interim migration stages. The interfaces between elements inside the system boundary, as well as interfaces to its operational environment and other systems should be clearly defined.

The SEMP should clearly define its range of control over the total system life cycle, and the planned stage gates to be passed in order to provide progressive assurance that the system will be accepted. The scope and extent of a SEMP can vary from one project to another.

A design and construction project may have a SEMP that extends from receipt of a reference design and SRS through to the defect and liability phase following hand over.

On the other hand, a build operate transfer (BOT) joint venture organisation may require a SEMP that extends from receipt of a BRS through to hand over of the system to TfNSW after operating and maintaining it for 25 years.

The SEMP should describe SE technical processes to be followed, including limits of control, responsibilities, deliverables, tools and controlling standards and procedures. SE technical processes include, but are not limited to, requirements, interface, RAM, safety, EMC and V&V management.
The SE organisation can vary significantly depending on the nature of the project change. An at-grade car park project may have minimal and rudimentary SE activities that may be carried out by the project manager. A medium complexity project may embed SE activities within the engineering organisation, with SE responsibility allocated to a lead engineer and design leads. A high complexity project with significant novelty and risk may require a specialist SE team to carry out the full range of technical and related specialised processes.

The SEMP should describe the various share information resources to be produced and used by the organisation during the delivery of the project. These include, but are not limited to, requirements database, technical interface register, interface control documents and so on.

A more detailed SEMP structure based on the INCOSE Handbook is proposed in Appendix A, and may be considered for project with high levels of complexity, novelty and risk.

However, the scope and content of a SEMP can vary significantly depending on the nature of the project.

11.5. **SEMP context**

The SEMP is not a standalone plan, and should be placed within the wider context of other plans associated with the planning and acquisition of new or altered systems. The SEMP has a contextual relationship with parent plans, peer plans and sub-plans.

11.5.1. **Parent plans**

T MU AM 06006 ST states the following requirement:

"The SEMP shall support the following 'parent' plans

- asset management plan that is scaled to network, line, discipline or asset type, depending on the scope of the system to be delivered
- project management plan, where the level of systems engineering activity is judged to be significant"

The asset management plan (AMP) describes the whole of asset life management activities, of which SE (and associated SEMP) forms a subset. The SE objectives, deliverables and activities in the SEMP should align with and support the achievement of the AMP objectives.

The project management plan (PMP) describes overall management arrangements (including SE, safety, procurement, and so on) for the planning and acquisition of a new or altered asset as a project. As PMP is the top-level plan for managing a change such as a new or altered system as part of a project, the SEMP should align with and support the PMP objectives.
11.5.2. Peer plans

T MU AM 06006 ST states the following requirement:

"The SEMP shall refer to and align with project peer plans"

A large project with high complexity, novelty and risk has the following peer plans to the SEMP, depending on the type of system to be delivered:

- project quality plan
- safety management plan (both system safety and project WHS)
- risk management plan (which may include safety risks)
- environmental and sustainability plan
- project work breakdown structure and schedule
- issues management plan (where issues are risks that have been realised)
- resource management plan (covering overall project resources)
- commercial plan (which may include procurement and cost management)
- procurement plan (especially on large projects with complex supply chains)
- cost management plan
- communications plan
- document/data management plan
- standards management plan
- configuration management plan
- change management plan
- CAD/GIS/BIM management plan
- maintenance and integrated logistics support (ILS) plan
- data preparation plan
- implementation plans
  - design management plan
  - manufacturing or fabrication plan (or similar)
  - construction or installation plan (or similar)
  - system integration/migration/staging plan (or similar)
  - inspection and test plan
11.5.3. Sub-plans

T MU AM 06006 ST states the following requirement:

"The SEMP shall be supported by systems engineering sub-plans, appropriate to the level of scope, novelty, complexity and risk of the proposed new or altered system"

A range of management sub-plans are typically produced and are followed within the SE management area.

For large, high complexity, novelty and risk projects, the following SE sub-plans are used:

- requirements management plan
- verification and validation plan
- interface management plan
- RAM(s) management plan
- system architecture management plan
- human factors integration plan
- EMC management plan
- software/data management plan

T MU AM 06006 ST states the following requirement:

"On low complexity projects, if some systems engineering activities are to be reduced or excluded altogether, then the project shall produce a coherent assurance argument to justify this decision"

Note: For smaller projects some sub-plans could be combined (or form sections of a SEMP), or may not be required. The person responsible for planning and managing systems engineering should assess the level of detail required, in consultation with the project manager, based on the expected level of novelty, complexity, scale and risk.
12. Systems engineering technical processes

A number of SE technical processes and related engineering management processes are followed over the system life cycle. While this document intends to align broadly with the SE technical processes defined in ISO15288, in practice within the transportation sector these processes take on slightly different descriptions, interpretations and focus.

SE technical processes in ISO15288 are generically defined to cover a wide range of industry sectors such as aerospace, defence, oil & gas, medical, automotive and transport.

For this reason, the generic ISO15288 processes are described in the context of how they will be implemented in the transport sector, in particular for TfNSW. This is called tailoring.

12.1. Process notation and design

T MU MD 00009 ST AEO Authorisation Requirements states the following requirement:

“An AEO shall have a systems engineering approach to the planning and delivery of its engineering services or products”

The AEO should interpret this requirement to mean that the SE approach is documented in a formal systematic way as part of their management systems, but does not prescribe exactly how this can be achieved.

AEOs with a high capability maturity in deploying SE technical processes in their integrated management systems should have documented their SE approach in a set of related technical procedures, manuals, guides or workflows.

While this SE guide does not prescribe a notation to document SE technical processes, the IDEF0 notation is proposed as a proven, clear, easily understood notation. At its simplest level, the IDEF0 notation uses the concepts shown in Figure 15.

![Figure 15 - IDEF0 Process Box Definition](insert figure)

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• Input: documents/deliverables, decision, or data from a predecessor function

• Function: a verb-noun statement describing the activity such as verify (verb) software (noun)

• Control: standards, requirements, regulations that govern how the function is performed

• Mechanism: who/what is responsible for executing the function (for example, designer, tester)

• Output: documents, assets/deliverables, decision, or data

Many successful organisations with a high capability maturity in systems engineering combine some variation of the IDEF0 notation with a swim lane format in their technical procedures to clearly identify ‘who performs what function, when, and how’ in the process.

More detailed explanation of the IDEF0 notation is available in the IDEF website (http://www.idef.com/idef0.htm).

12.2. Stakeholder requirements definition process

T MU AM 06006 ST states the following requirement:

"A project shall implement a defined process, responsibilities, structure, tools and deliverables for management of requirements across the system life cycle"

Requirements management (RqM) arrangements should be documented. Depending on the scope, novelty, complexity and risk of the system to be delivered, RqM may be documented based on the following levels:

• High: a standalone requirements management plan (RqMP)

• Medium: a RqM section within a systems engineering management plan (SEMP)

• Low: for simple projects that involve mostly a single discipline using type approved products in a standard configuration, requirements management may be limited to a section of a project plan or a project engineering management plan.

The project should also have a process for identifying system safety requirements, which should be specifically identified and managed in a hazard log.

T MU AM 06006 ST states the following requirement:

"The need or goals for new or altered service capability shall be identified"

TSD, CED and FRD are involved in identifying the enterprise goals and needs in order to achieve a new or altered service capability. However, in some cases it is possible that the O&M may perform this activity (for example, Sydney Trains developing the Rail Operations Centre).

This activity is the trigger for the investment life cycle, and should align with the long term vision and enterprise objectives of TfNSW and the state of NSW as a whole.
T MU AM 06006 ST states the following requirement:

"A baseline business requirements specification (BRS) shall be produced for investment gate 2 in consultation with relevant authorised stakeholders"

The BRS is produced by PD, with stakeholder inputs from TSD, CED, FRD and the O&M. In some cases the BRS may be produced by the project delivery organisation. In other cases the O&M may still encounter situations where it may lead to the development of the BRS (for example, Sydney Trains specifying the ROC business requirements).

Regardless of who produces the BRS in any particular situation, the following activities should be carried out in order to produce a baseline BRS:

- define the operational capability (operational performance) to support the need or goals
- produce an operations concept document (OCD) that describes the operational activities required to support the operational capability
- produce a maintenance concept document (MCD) that describes the maintenance activities required to support the operational capability
- produce a business case and associated business requirements specification (BRS)
- conduct all performance modelling and analysis to support production of these deliverables

T MU AM 06006 ST states the following requirement:

"The entity responsible for producing the BRS shall submit the BRS to the TfNSW configuration management and asset assurance committee (CMAAC) for acceptance and endorsement"

The BRS should be accepted and endorsed by the CMAAC to assure that network asset integrity is retained in all these cases as it involves significant changes to the transport network.

T MU AM 06006 ST states the following requirement:

"A system requirements specification (SRS) shall be produced for CMAAC gate 2 approval, in consultation with relevant authorised stakeholders"

The SRS is produced by the project delivery office, usually TPO, often with support from an experienced AEO acting as the technical advisor and with stakeholder inputs obtained from the O&M and other TfNSW stakeholders as needed.

Depending on the commercial contract, the delivery organisation responsible for developing the SRS may not always be TPO acting as the procuring organisation.

In some cases the SRS may be produced by the O&M.

The following activities are carried out in order to produce a system requirements specification:

- develop the concept design up to a (costed) reference design
- develop the system requirements specification (SRS)
• develop the P90 cost estimate
• prepare and issue an invitation to tender (ITT)

Further guidance on SRS is provided in T MU AM 06007 GU Guide to Requirements Definition and Analysis.

12.3. Requirements analysis process

When the tender is awarded, the contracting AEO(s) may choose to follow the reference design, or to develop its own design, provided it meets the BRS and SRS requirements.

T MU AM 06006 ST states the following requirement:

“As appropriate for the project, system requirements shall be allocated from the SRS into subsystem requirements (SSRs), to synthesise and develop detailed subsystem designs”

When the contract is awarded, the AEO should analyse the system requirements in the SRS, and determine the appropriate system design solution to achieve these requirements. The AEO may choose to adopt the reference design solution associated with the SRS, or it may choose to develop its own solution.

As the system architecture evolves, the system requirements are allocated to subsystems such as rolling stock, signalling and control, telecommunications, electrical traction, track and structures. The allocation of requirements to these subsystems results in the development of subsystem requirements that can be traced back to system requirements.

The traceability of these requirements should be managed formally using a tool that is suitable for the complexity of the new or altered system to be delivered.

T MU AM 06006 ST states the following requirement:

“Business requirement specifications shall identify and trace back to informing documents and source documents. For example policies, strategies and long term transport plans”

The project should at all stages of the development of the new or altered system, be able to trace the development of the design back to the key source documents that resulted in the initiation of the project (for example, policy, strategy, long term plans).

The project should also be able to trace the development of the evolving system to informing documents such as hazard logs, assumptions, dependencies, constraints, domain knowledge, and value for money analysis.

T MU AM 06006 ST states the following requirement:

“An appropriate requirements management tool shall be used to manage the categorisation, allocation, changes, traceability, verification and validation of business, system and subsystem requirements”
A suitable tool should be used to perform the following tasks:

- categorising requirements (functional, performance, safety, operational, RAM)
- allocating requirements to subsystems as the design evolves
- managing changes to requirements during the design development
- tracing requirements through from high level business requirements to detailed subsystem design
- verifying and validating these requirements

T MU AM 06006 ST states the following requirement:

"Selection of the type of requirements management tool shall be based on complexity, scale and TfNSW contractual requirements"

For high-complexity projects which may contain a large number of requirements, a dedicated Commercial Off The Shelf (COTS) requirements management tool is recommended as it becomes increasingly difficult for the following tasks:

- manage traceability and allocation of requirements as a system design evolves
- record all verification and validation evidence
- change requirements
- manage requirement baselines throughout the system acquisition phase

For lower complexity projects with fewer requirements and simpler interfaces, the requirements may be managed in a spreadsheet or similar tool (RATM/RVTM).

T MU AM 06006 ST states the following requirement:

"The requirements management tool shall be able to exchange requirements information using a common interchange format with TfNSW requirements databases and associated schema"

TfNSW, in particular ASA, PD and TPO, have taken a strategic decision to adopt a common RqM tool, schema and process for seamless requirements management between the various divisions. The supply chain should ensure that requirements under its control are defined in a common format that permits easy exchange with TfNSW.

This common schema is defined in T MU AM 06004 ST Requirements Schema.

Further guidance is provided in T MU AM 06007 GU Guide to Requirements Definition and Analysis.
12.4. System architectural design process

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements that define the synthesis and development of system level requirements into a system architecture (functional, physical and geographic)"

The system architecture forms the conceptual design framework, based on which detailed system and subsystem design are based.

For systems involving high complexity, a functional architecture or model is good to start with to ensure that all system functions are identified and sufficiently defined.

The system is further defined by identifying the proposed physical solution architecture and allocating the functions to the physical system elements or subsystems.

The physical system elements or subsystems are then allocated to geographical locations to form the geographical (or deployment) architecture.

Additional effort may be involved in defining system and subsystem interfaces as part of the system architecture design process.

When the functional, physical, geographical and interface architecture design are defined, the project then progresses to detailed design of each of the constituent subsystems as part of the implementation process.

Examples of functional, physical, geographical and interface architectures that are synthesised and developed under the system architectural design process are described in Section 7.5, Section 7.6, Section 7.7 and Section 7.8.


12.5. Implementation process

The implementation process involves detailed design development of each of the subsystems, specification and procurement of materials and OEM equipment, fabrication and manufacturing at OEM supplier factory premises, shipping of fabricated material and OEM equipment to site, and installation and assembly on site.

The level of SE within the implementation process is limited to verification of designs, factory acceptance and site acceptance.
12.6. **Interface and integration process**

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements based on a well-defined process, responsibilities, structure, tools and deliverables associated with system interfaces"

The complex, multi-disciplinary nature of engineering projects and systems requires that technical interfaces (and organisational and stakeholder interfaces) should be clearly defined, along with their ownership and control.

Interfaces should be analysed and synthesised into the overall system design. For high novelty and complexity systems, a dedicated interface management plan is required. For simpler projects, interface management may be part of an engineering management plan.

In the SE management context, interface management refers to the managing technical system interfaces, and is not limited to organisation or contract interfaces.

T MU AM 06006 ST states the following requirement:

"A project shall ensure that all system interface requirements under its control are identified, captured and managed"

Technical interface requirements, as a type of system requirement, should be identified during the definition of the system solution. This should be captured into a central repository that is managed for change and verified that these requirements are met.

Interface requirements are identified and captured by functional and physical architecture models and stakeholder meetings and interviews.

Interface requirements are managed by interdisciplinary design reviews and checks (IDR and IDC) and following standards (where standards adequately define known interfaces).

T MU AM 06006 ST states the following requirement:

"System interface reviews and checks shall be conducted at appropriate stages of the system design and implementation"

When the system requirements are allocated to individual subsystems (and the specialist disciplines responsible for designing each subsystem), the risk of individual subsystem designs diverging from each other in terms of how they integrate into the wider system may exist.

Regular interdisciplinary design reviews and checks should be facilitated to ensure that interfaces defined in the earlier system architecture are still achievable in terms of the required functionality and performance.

Depending on the level of novelty and complexity, these interdisciplinary reviews could be facilitated by the design manager or by a dedicated interface manager for high complexity.
T MU AM 06006 ST states the following requirement:

"A project shall identify and manage system interface risks and their causes, consequences and controls that may have adverse health, safety or environment impacts on users"

Interface risks may include both safety and non-safety related risks. Technical system interface risks may be identified during preliminary hazard identification (HazId), followed by a more detailed interface hazard analysis (IHA).

All technical interface risks should be managed in the same way, by assigning controls and owners to assure that the risks are controlled to level that is reasonably practicable.

T MU AM 06006 ST states the following requirement:

"Control and specification of system interfaces shall be via interface control documents (ICDs) and interface requirements specifications (IRS)"

For high complexity systems, specification and planning of interface development and control should follow a structured approach. This is achieved by identifying all key subsystems within the overall system, and arranging them in a matrix of rows and columns. Each element of the matrix represents a technical or system interface to be controlled. An example of an ICD matrix is presented in Appendix F.

When all interfaces are identified in the ICD matrix (also called an N2 matrix), each interface should be defined in terms of who is responsible for each end of that interface and who takes the lead on assuring that interface. This is done via the interface control document (ICD). High level functionality and performance requirements should be identified in the ICD.

As the system architecture progresses, and depending on the level of novelty, complexity and risk, an interface requirement specification (IRS) may be required to further define the detailed functional and performance requirements.

Examples of where this level of interface definition and control would be required include interfacing a particular signalling interlocking product type to the Radio Block Centre (RBC) for an ETCS-L2 application. Details of the data telegram and associated protocols would need to be defined in the IRS, to allow the interlocking to communicate with the RBC unit.

The IRS is most suitable for electrical and electronic programmable systems that rely on embedded software.

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements to plan and carry out the safe, controlled integration of all elements of the new or altered system of interest"

Systems integration, while carried out on the right hand side of the V-lifecycle model after installation and before commissioning, is an activity that should be planned well in advance, on the left hand side of the V-lifecycle model.
Due to the complex nature of the live operational railway, especially with brown field projects, it is not possible to integrate all systems in a single stage. A systems integration plan should take the interfaces defined in the ICDs (and IRSs if necessary), to develop a series of planned intermediate stages. This is done in order to bring the various subsystems together in a controlled manner, including the specification of integration tests.

The system (and subsystem) designer should cooperate with the testing and commissioning staff to plan these integration and testing activities, along with acceptance criteria.

During system integration, designers should be available to support testing and commissioning staff in order to ensure that the original interface design intent is met, and to authorise changes required as a result of issues that may arise during integration and testing.

With some systems, a significant amount of the system integration and testing may be carried out off site at the supplier’s factory premises, as factory integration testing.

T MU AM 06006 ST states the following requirement:

"On high-complexity projects, where it is not possible to commission into operation the entire new or altered system in one stage, a project shall develop and follow a multi-staged systems migration and integration approach"

For high-complexity projects it may not be possible to commission the entire new or altered system into operation in one stage onto the rail network. The most practical approach used for introducing new or altered assets, is to introduce elements of the system via a series of interim configuration states or stage works under possessions. This stage works may be described in a stage works plan or migration plan or integration plan.

T MU AM 06006 ST states the following requirement:

"A project shall identify, plan, schedule and control interim configuration states and migration from one configuration state to the next, up to commissioning of the fully integrated system"

These migration or interim configuration stages should be carefully planned, to ensure that the right staff, processes, tools, equipment and assets are ready for staged integration and testing. The systems integration and migration plan should be supported by a detailed schedule of integration activities and controls.

Where the change introduced by an interim configuration state is assessed as significant, then it may need to be escalated above the delivery organisation's CCB for approval by the CMAAC as an interim commissioned system (that is CMAAC Gate 5). In most cases, interim configurations are managed as a change via the local delivery organisation's CCBs.

Further guidance is provided in the TS 10507 AEO Guide to Systems Integration.
12.7. **Verification process**

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements based on a well-defined verification and validation (V&V) process, responsibilities, structure, tools and deliverables"

Depending on the system novelty and complexity, a verification and validation management plan may be developed and implemented. This V&V plan should describe the process and methods to be used, V&V organisation and responsibilities, the structure of expected V&V evidence, how this V&V evidence is captured (in a tool), and planned deliverables (reports).

Verification activities may include modelling, simulation, mock-ups, design reviews, independent checking and verification, inspection, testing, auditing and surveys.

Verification deliverables may include a verification plan (possibly a V&V Plan, since validation is managed with verification), and one or more verification reports (or V&V reports) depending on system complexity, novelty of products and configuration, and number of migration stages.

For simpler projects, verification may be embedded within the SEMP, engineering management plan or even the project management plan.

T MU AM 06006 ST states the following requirement:

"A project shall plan V&V activities early in the system life cycle, starting with tracing goals and operational capabilities to the development of the business requirements specification, then to a system requirements specification and finally a subsystem requirements specification"

The verification process spans through the system life cycle from the concept and specify stage through to system integration and testing.

Verification should begin as soon as the BRS is produced. This should be done in order to begin demonstrating that business requirements are identified and defined that satisfy and are traceable to original user needs (demand analysis) defined at the very beginning of the system life cycle.

Furthermore, during requirements definition (BRS and SRS), the project should determine the V&V methods and criteria that may be used later to assure that requirements are achieved, the responsible person for each activity, and when these activities are planned to take place.

T MU AM 06006 ST states the following requirement:

"A project shall establish and maintain a method of recording all V&V activities and results, and trace these to originating requirements"

TfNSW projects use a specialised requirements management tool to capture both requirements information and evidence details of the verification activities that are used to progressively assure that requirements are met during design, construction, testing and commissioning stages.
TfNSW has adopted DOORS as its standard requirements management tool and has specified and configured a schema in DOORS to manage verification activities and evidence.

TfNSW does not mandate the use of any proprietary RqM tool (such as DOORS) on AEOs and the supply chain, but does require all requirement and V&V information to be presented in a structure that facilitates seamless transfer into the TfNSW DOORS project repository.

Further guidance is provided in T MU AM 06004 GU Requirements Schema and TS 10506 AEO Guide to Verification and Validation.

12.8. Transition process

Within the TfNSW context, transition means the activities associated with transferring the system into operational use which is achieved by the commissioning and operational readiness activities. The operational readiness report reflects the following transitioning activities:

- all commissioning tests completed and successful
- all safety risks controlled or transferred to and accepted by the O&M
- operational processes and procedures updated
- operator manuals complete and provided
- maintenance manuals complete and provided
- operators trained and certified on the new system
- maintainers trained and certified on the new system

12.9. Validation process

While ISO 15288 separates the verification and validation technical processes, this document proposes to combine them as closely related activities.

Verification and validation often use the same processes, tools and methods, but for achieving different assurance outcomes at different stages in the project life cycle.

The verification process spans through the system life cycle from the specify stage through to system integration, whereas validation is used as the final demonstration that the business requirements are met for system acceptance.

Depending on the level of novelty and risk, early validation of business and system requirements using models, mock-ups and simulations, prior to commencing detailed design may be performed.

Refer to Section 12.7 for both verification and validation.
12.10. Operation process

Project perspective and O&M perspective are the two aspects to operations process that systems engineering should consider.

During the plan, specify, develop and acquire stages of a new or altered system, the project should consider the system operations over its full operational life time (operability and operational availability analysis).

Following acceptance of the new or altered system from the project, the O&M should continue to manage the system and its configuration, including application of SE management principles to ongoing operations.

12.11. Maintenance process

Project perspective and O&M perspective are the two aspects to maintenance process that systems engineering should consider.

During the plan, specify, develop and acquire stages of a new or altered system, the project should consider the system maintenance over its full operational lifetime (maintainability and logistic support analysis). This should include consideration of many different maintainability aspects, such as (but not limited to) the following:

- standardisation and commonality of spares
- interchangeability between multiple asset owners
- accessibility considerations to the maintainable item
- special tools and test equipment required
- built-in-test (BIT) capability
- maintenance and fault diagnostic aids
- failure isolation

Following acceptance of the new or altered system from the project, the O&M should continue to manage the system and configuration, including application of SE management principles to ongoing maintenance.

12.12. Disposal process

In the case of brown field projects, the decommissioning and disposal of life-expired or obsolete systems is often planned, designed and executed concurrently with the planning, design and installation of new or altered systems.

Disposal of systems is not carried out by the same organisation that introduced those systems in the first place; often separate in time by decades of operations and maintenance.
12.13. Process mapping to the life cycle

The SE processes described in Section 12, and other SE related engineering processes, are active at different stages in the total system life cycle. Some processes may map to one or more specific stages, whereas others may map and be active across the full life cycle. Additionally, where an SE or SE related process is active over multiple stages, it may be more active at one point and less active at another. This mapping and level of activity can vary from one system or project type to another, and depends on technology, complexity, novelty, risk and other factors. Figure 16 shows an example of the mapping of SE activities to system life cycle stages.

Figure 16 - SE process mapping to life cycle

13. Technical specialty processes

The INCOSE SE Handbook mentions a range of technical specialty processes, but the most significant ones from a transport perspective are as follows:

- EMC management
- RAM management
- Human factors integration management
13.1. **EMC management**

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements for assuring electromagnetic compatibility (EMC) during the specification, design, integration or testing of electrical and electronic systems involving electromagnetic interference (EMI) threats or victims"

Electromagnetic compatibility (EMC) is a systems-level attribute that can be highly complex and difficult to model and verify prior to commissioning. The risk of EMC issues arising with the introduction of novel electronic systems on the modern transport system is tangible.

Where type approved products are used in standard configurations, EMC may be demonstrable by complying with engineering standards and codes of practice and some testing. Where novel products are introduced or type approved products are configured in a novel way, then additional modelling, analysis and testing is required in order to assure EMC risk is controlled.

The level of EMC effort should be scalable according to the novelty, complexity and risks associated with the introduction of new or altered systems.

For an electrical traction supply engineer, EMC may relate to modelling and analysis of a novel 25 kV ac traction system introduced onto a section of the rail network that was previously using 1500 V dc traction, or was not electrified. The effects of electromagnetic induction on parallel conductive paths such as fences, pipelines, and copper cables should be analysed and appropriate EMC controls put in place.

For a signal engineer, EMC may relate to analysis of external EMI threats to signal interlocking, remote control systems, copper lineside cables and other trackside equipment.

For a telecommunications engineer, EMC may relate to the introduction of audio hearing loops on station platforms, close to traction OHW and train detection systems, and therefore the need to analyse and test for in-band interference between these systems.

For a structural engineer, EMC may relate to the need to cooperate with the electrical traction supply engineer in identifying earthing and bonding arrangements for a bridge and the effects of electrolysis from dc traction earth return currents on the structure foundations.

For a contractor designing and building an at-grade car park outside the rail corridor, a need for any form of EMC management may not be present.

For more detailed guidance on management of EMC, refer to TS 10504 AEO Guide to Engineering Management. For the purposes of railway engineering, the EN50121 series of standards are treated as the guiding standards.
13.2. **RAMS management**

For the purposes of this guide, the term reliability, availability, maintainability and safety (RAMS) is used to define an integrated management approach. However, this guide is limited to RAM and not the safety element of RAMS management, as safety assurance is addressed in TS 20001 *System Safety Standard for New or Altered Assets*.

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements that define the reliability, availability, maintainability and safety (RAMS) process, responsibilities, structure, tools and deliverables"

The need for and application of RAM management has different meaning to different disciplines. The impact of RAM management on planning and acquisition of new or altered systems and the specific disciplines that support the system design should be understood.

T MU AM 06006 ST states the following requirement:

"A project shall consider RAMS performance and how it relates to operational performance for novel systems early in the system life cycle, starting with development of the operational concept definition and maintenance concept definition"

For a structural engineer, RAM may relate to finite element modelling and analysis of a bridge structure to determine stress points and selection of corrosion-resistant materials to ensure that the bridge meets or exceeds a 100 or 200 year lifetime.

For a track engineer, RAM may relate to the selection of harder wearing steel rail (such as CrMn or head-hardened rail) to achieve longer wear life under increased axle loads. This will have longer term impacts on future rail grinding and profiling programs that incur significant cost to the O&M.

For an electrical traction supply engineer, RAM may relate to the modelling and analysis of the traction power supply network, including feeders from the bulk electricity suppliers. This ensures that all traction supply points to the railway are fed from at least two geographically diverse points. This is done in order to achieve a required power supply availability and traction current performance under normal, degraded and emergency modes of operation.

For a signal engineer, RAM may relate to the reliability modelling and analysis of a redundant remote control or interlocking architecture to assure availability or the selection of LED signals to improve reliability over filament lamp signals.

For a telecommunications engineer, RAM may relate to reliability modelling and analysis of a redundant optical fibre backbone network and selection of a ring, star or network architecture to achieve sufficient network availability under normal and degraded modes of operation.

T MU AM 06006 ST states the following requirement:

"A project shall consider human reliability factors as part of the overall reliability of the system"
Human element of overall system reliability should be considered in the development of a system and the achievement of its requirements. Humans are susceptible to varying levels of performance due to many factors that affect their reliability in carrying out functions, including stress, fatigue, distraction, workload, environment, competence, and so on.

T MU AM 06006 ST states the following requirement:

"A project shall use RAMS modelling to appropriately support option selection and development and preliminary system design, to ensure that the new or altered system will meet the stated operational capability and provide value for money over the designed system lifetime"

Where the new or altered system is specified to use proven type approved products in standard approved configurations, the need for RAMS modelling may not be necessary. If the preferred option is specified by TfNSW due to logistic reasons, then there is little value to be gained by the AEO (typically the design consultant) performing detailed RAMS modelling and analysis in order to obtain numeric RAMS targets.

Where TfNSW has provided numeric RAMS targets to be met by the contracting parties, then it is necessary for the design AEO to develop a RAM model to verify during design that the system is likely to meet those targets.

T MU AM 06006 ST states the following requirement:

"A project shall consider sustainable operation and maintenance of the new or altered system over the full system life cycle"

In order to achieve a system-level assurance of RAM, a RAM manager or engineer should coordinate all individual RAM analysis performed at subsystem level where the level of system complexity, novelty and risk justifies this.

For more guidance on the management of RAM, refer to TS 10504 AEO Guide to Engineering Management, EN 50126 RAMS, and AS/NZS ISO/IEC 15288.

13.3. HFI management

T MU AM 06006 ST states the following requirement:

"A project shall implement management arrangements for assuring human factors integration (HFI) during the specification, design, integration or testing of the new or altered system"

The study or human factors and ergonomics and the interaction of humans with designed and built systems is a complex and specialised field. This is carried out by specialist professionals with the necessary blend of knowledge in human psychology, biomechanics and cognitive skills to support the development of systems that successfully work with human operators.

The AEO should be aware of the need for some degree of HFI in the development of the solution and the assurance that risks (including safety) are not introduced at the human-machine interface.

14. Related life cycle processes

Depending on the scope, complexity, novelty, risk and contractual arrangements of a system asset-related engineering project, relating the core SE technical processes to other related processes, including the following is necessary:

- agreement processes
- enterprise processes
- project processes
- tailoring processes

14.1. Agreement processes

Agreement processes include the acquisition process and supply process.

In the acquisition process, SE should communicate and coordinate efforts with TfNSW procurement and its associated processes and ensure that system specifications are complete, correct and coherent with the request for tender. The systems engineer may produce and review tender specifications and review tender compliance to those specifications.

In the supply process SE should ensure that sufficient communication and coordination occurs with the supply chain in terms of communicating system-level requirements down to the suppliers and ensuring that assurance of delivery against system requirements is provided by suppliers.

14.2. Organisational project-enabling processes

Management of SE to support the planning and acquisition of new or altered system requires an understanding of, and interaction with, TfNSW enterprise-level processes to ensure that the change is introduced within the overall enterprise management framework. These enterprise or project-enabling processes include the following:

- life cycle model management process (TfNSW asset management processes)
- infrastructure management process (TfNSW asset management processes)
- project portfolio management process (PD processes)
human resource management process
quality management process (TfNSW and agencies’ QMS)

14.3. Project processes

Management of SE on a project should be planned and carried out within the broader context of other project management processes. The project processes that could have a direct interaction with SE management processes include the following:

- project planning process (PD, TPO and O&M project planning processes)
- project assessment and control process (TPO and O&M project control processes)
- project decision management process (TPO and O&M project processes)
- project risk management process
- project configuration management process
- project information management process
- project measurement process

14.4. Tailoring process

Tailoring and scaling of the application of SE as defined in T MU AM 06006 ST Systems Engineering, to a project should balance assurance of delivery of stakeholder/user requirements with value for money engineering.

The person responsible for planning and managing SE should adopt a pragmatic, value for money approach in implementing SE on a project. The systems engineer should assure delivery of a new or altered system that meets the business and stakeholder requirements in the most cost-effective manner.

If the project involves a system that uses type approved products in a standard configuration that are successfully introduced before, then it is unnecessary to model RAM or EMC and the level of human factors integration (HFI) may be limited.

Similarly, for a simple ‘single-discipline’ project such as doubling the OHW contact wire to achieve increased current capacity, the need to develop a system architecture model is unnecessary.
15. **SE tools**

The management of SE on high complexity and high novelty projects requires the selection and implementation of appropriate tools to support various SE management activities.

These SE tools should be selected based on the value for money that they provide in improving efficiency and assurance that the system requirements are complete, coherent and achieved.

Depending on the nature of the problem or need to be addressed by the acquisition of a new or altered system, tools can be selected and implemented to support SE management as follows:

- requirements management tools
- system performance modelling tools
- system architecture visualisation and management tools
- safety case tools (such as using Goal Structuring Notation)
- RAMS tools (such as FTA, RBD and FMECA)
- risk management tools
- human factors tools
- EMC modelling and analysis tools
- configuration management tools
- verification test management tools
- systems integration tools, including software and hardware integration tools
Appendix A  Example of SEMP structure

A.1.  SEMP structure (INCOSE SE Handbook edited)

1. Organisation of the project and how SE interfaces with the other parts of the organisation
2. Responsibilities and authority of the key SE positions
3. System boundaries and scope of the project
4. Assumptions and constraints
5. Key technical objectives
6. Risk and opportunity plan, assessment, and methodology
7. Verification and validation planning
8. Configuration management planning
9. QA planning
10. Infrastructure support and resource management (that is, facilities, tools, IT, personnel, and so on.)
11. Reliability, availability, maintainability, supportability, and integrated logistics support (ILS)
12. Survivability
13. EMC, radio frequency management, and electrostatic discharge
14. Human factors integration
15. Safety, health and environmental impact
16. System security
17. Manufacturability or constructability
18. Test and evaluation
19. Testability and integrated diagnostics
20. Computer resources
21. Transportability
22. Other engineering specialties that determine performance and functional requirements
Appendix B  Examples of SE application effort and scaling

Table 2 identifies a range of typical rail engineering projects and the level of SE to be applied. The reader should note however, that there may be variations on each of these scenarios, and engineering discretion is required in order to determine the scale of SE to apply.

### Table 2 – Level of SE to be applied on rail engineering projects

<table>
<thead>
<tr>
<th>Level</th>
<th>Project Example</th>
<th>Project Scale ($/time)</th>
<th>Complex</th>
<th>Novelty</th>
<th>Unmitigated Project Risk</th>
<th>SE Effort</th>
<th>Interface</th>
<th>V&amp;V</th>
<th>Sys Arch</th>
<th>RAMS</th>
<th>EMC</th>
<th>HFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>At-grade car park (away from corridor)</td>
<td>Small</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Light</td>
<td>L L L L</td>
<td>L   L -</td>
<td>L -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OHW (new/altered)</td>
<td>Small</td>
<td>Low</td>
<td>Low</td>
<td>Light</td>
<td>L L L L L L</td>
<td>L -</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HV Feeder 66/33/11kV (new/altered)</td>
<td>Small</td>
<td>Low</td>
<td>Low</td>
<td>Light</td>
<td>L L L L L M</td>
<td>M -</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multi-story car park (adjacent to corridor)</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>M M M L L</td>
<td>L   - M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traction Substation (single)</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>M M M M M</td>
<td>M   M M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Junction Upgrade (single)</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>M M M M M</td>
<td>M   M M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Station (small to medium, new/altered, single)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>M M M M M</td>
<td>M   M M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport Interchange (major, single)</td>
<td>Large</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>H H H H H</td>
<td>H   H M M</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stabling Yard (single)</td>
<td>Large</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>H H H H H</td>
<td>H   M M H</td>
<td>M H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program</td>
<td>Major Track Renewals (corridor/network)</td>
<td>Large</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Light</td>
<td>L M M L M</td>
<td>H   M H</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport Access Program (network)</td>
<td>Large</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>M H M M M</td>
<td>L   M L</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Automatic Train Protection (network)</td>
<td>Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advanced Train Control System (network)</td>
<td>Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digital Train Radio System (network)</td>
<td>Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>New Fleet Procurement (network/line)</td>
<td>Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traction Power Supply Upgrade (network)</td>
<td>Large</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td>M</td>
<td></td>
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<tr>
<td></td>
<td>Signalling Technology Upgrade (network)</td>
<td>Variable</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corridor/Line Upgrade (brown field)</td>
<td>V Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corridor/Line New Build (green field)</td>
<td>V Large</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portfolio</td>
<td>Sydney's Rail Future (network/multiple programs)</td>
<td>V Large</td>
<td>V High</td>
<td>V High</td>
<td>V High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sydney's Light Rail Future (CBD &amp; SELR, Newcastle, Parramatta)</td>
<td>V Large</td>
<td>V High</td>
<td>V High</td>
<td>V High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
<td>H H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sydney's Ferry Future (Wharves and Fleet)</td>
<td>V Large</td>
<td>V High</td>
<td>V High</td>
<td>V High</td>
<td>Heavy</td>
<td>H H H H H</td>
<td>H   H H</td>
<td>H H</td>
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<td></td>
</tr>
</tbody>
</table>

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Appendix C  Specific and generic system life cycles

C.1.  Multiple system life cycles

Figure 17 – Multiple system life cycles

THESE V-DIAGRAMS ILLUSTRATE THE COMPLEX RELATIONSHIP BETWEEN A GENERIC PRODUCT DEVELOPMENT/ADAPTATION LIFECYCLE, A SPECIFIC PROJECT APPLICATION LIFECYCLE, AND ONGOING SYSTEM/PRODUCT SUPPORT LIFECYCLE CHANGES.
C.2. **V-life cycle model for multi-disciplinary, staged rail engineering project**

*Figure 18 – V-life cycle model for multi-disciplinary, staged rail engineering project*
Appendix D  Example of a railway system

Figure 19 – Example of a railway system
Appendix E  TfNSW asset classification scheme

Figure 20 – TfNSW asset classification scheme (extracted from T MU AM 02001 ST Asset Information Management Standard)
## Appendix F  Example of interface control document matrix

<table>
<thead>
<tr>
<th>ICD MATRIX</th>
<th>Signalling Systems</th>
<th>Telecoms &amp; Data Network</th>
<th>Control Systems</th>
<th>Electrical Substation</th>
<th>Overhead Wiring</th>
<th>Track Systems</th>
<th>General Civils</th>
<th>Bridges &amp; Structures</th>
<th>Stations &amp; Interchanges</th>
<th>Yards &amp; Depots</th>
<th>Rolling Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalling Systems</td>
<td>1.01 ABC Entity</td>
<td>XXX-ICD-10 Joe Bloggs</td>
<td>XXX-ICD-11</td>
<td>Joe Bloggs</td>
<td>1.03 ABC Entity</td>
<td>XXX-ICD-12</td>
<td>Joe Bloggs</td>
<td>1.04 ABC Entity</td>
<td>XXX-ICD-13</td>
<td>Joe Bloggs</td>
<td>1.05 ABC Entity</td>
</tr>
<tr>
<td>Telecoms &amp; Data Network</td>
<td>2.01 ABC Entity</td>
<td>XXX-ICD-20 Joe Bloggs</td>
<td>2.02 ABC Entity</td>
<td>XXX-ICD-21 Joe Bloggs</td>
<td>2.03 ABC Entity</td>
<td>XXX-ICD-22 Joe Bloggs</td>
<td>2.04 ABC Entity</td>
<td>XXX-ICD-23 Joe Bloggs</td>
<td>2.05 ABC Entity</td>
<td>XXX-ICD-24 Joe Bloggs</td>
<td>2.06 ABC Entity</td>
</tr>
<tr>
<td>Overhead Wiring</td>
<td>5.01 ABC Entity</td>
<td>XXX-ICD-50 Joe Bloggs</td>
<td>5.02 ABC Entity</td>
<td>XXX-ICD-51 Joe Bloggs</td>
<td>5.03 ABC Entity</td>
<td>XXX-ICD-52 Joe Bloggs</td>
<td>5.04 ABC Entity</td>
<td>XXX-ICD-53 Joe Bloggs</td>
<td>5.05 ABC Entity</td>
<td>XXX-ICD-54 Joe Bloggs</td>
<td>5.06 ABC Entity</td>
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<tr>
<td>General Civils</td>
<td>7.01 ABC Entity</td>
<td>XXX-ICD-70 Joe Bloggs</td>
<td>7.02 ABC Entity</td>
<td>XXX-ICD-71 Joe Bloggs</td>
<td>7.03 ABC Entity</td>
<td>XXX-ICD-72 Joe Bloggs</td>
<td>7.04 ABC Entity</td>
<td>XXX-ICD-73 Joe Bloggs</td>
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<tr>
<td>Bridges &amp; Structures</td>
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<td>XXX-ICD-80 Joe Bloggs</td>
<td>8.02 ABC Entity</td>
<td>XXX-ICD-81 Joe Bloggs</td>
<td>8.03 ABC Entity</td>
<td>XXX-ICD-82 Joe Bloggs</td>
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<td>Stations &amp; Interchanges</td>
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<td>XXX-ICD-90 Joe Bloggs</td>
<td>9.02 ABC Entity</td>
<td>XXX-ICD-91 Joe Bloggs</td>
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<tr>
<td>Yards &amp; Depots</td>
<td>10.01 ABC Entity</td>
<td>XXX-ICD-100 Joe Bloggs</td>
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