T MU AM 06006 GU

Guide

Systems Engineering

Version 2.0

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Standard governance

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Document history

Version	Summary of changes
1.0	First issued 05 May 2015
2.0	Second issue. Changes from the previous version include: • inclusion of 'demand/need' stage in TfNSW asset life cycle • removal of references to specific TfNSW divisions • change focus from heavy rail to multi-mode

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Preface

The Asset Standards Authority (ASA) is a key strategic branch of Transport for NSW (TfNSW). As the network design and standards authority for NSW Transport Assets, as specified in the *ASA Charter*, the ASA identifies, selects, develops, publishes, maintains and controls a suite of requirements documents on behalf of TfNSW, the asset owner.

The ASA deploys TfNSW requirements for asset and safety assurance by creating and managing TfNSW's governance models, documents and processes. To achieve this, the ASA focuses on four primary tasks:

- publishing and managing TfNSW's process and requirements documents including TfNSW plans, standards, manuals and guides
- deploying TfNSW's Authorised Engineering Organisation (AEO) framework
- continuously improving TfNSW's Asset Management Framework
- collaborating with the Transport cluster and industry through open engagement

The AEO framework authorises engineering organisations to supply and provide asset related products and services to TfNSW. It works to assure the safety, quality and fitness for purpose of those products and services over the asset's whole-of-life. AEOs are expected to demonstrate how they have applied the requirements of ASA documents, including TfNSW plans, standards and guides, when delivering assets and related services for TfNSW.

Compliance with ASA requirements by itself is not sufficient to ensure satisfactory outcomes for NSW Transport Assets. The ASA expects that professional judgement be used by competent personnel when using ASA requirements to produce those outcomes.

About this document

This document provides guidance in complying with the requirements stated in T MU AM 06006 ST *Systems Engineering* standard.

This guide is a second issue.

This guide is revised to include the demand/need stage in TfNSW asset life cycle and modify the contents to change the focus from heavy rail to multi-mode.

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1. Introduction

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

SE 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 life cycle and all stages from both an international standard (AS/NZS ISO/IEC/IEEE 15288:2015 *Systems and software engineering - System life cycle processes*) perspective and the TfNSW asset life cycle perspective. The need for, and structure of a systems engineering management plan (SEMP) is identified, along with its context to other relevant plans.

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.

The benefit of SE 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. The capability maturity in SE across a spectrum of engineering organisations applying for Authorised Engineering Organisation (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 AEOs with emerging capability maturity to better understand the need for SE, 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.

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2.1. Scope

The SE guide sets out the structure and practice for carrying out SE activities associated with planning, acquisition, development, utilisation and disposal of new or altered transport systems.

This guide should be read in conjunction with AS/NZS ISO/IEC/IEEE 15288:2015, the *INCOSE Systems Engineering Handbook*, and T MU AM 06006 ST *Systems Engineering*.

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.

2.2. Application

SE is a methodology for engineering complex integrated systems and should not be considered as a separate department, discipline or role.

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

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

This guide applies to the following:

- all entities within TfNSW and the supply chain involved in the planning, acquiring, operating, maintenance 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
- AEOs in the supply chain involved in the planning, acquiring, operating, maintenance and disposal of new or altered transport systems

The users of this guide should understand and apply the relevant systems engineering management activities described in this document. The concepts, principles and processes described in this SE guide should be tailored and scaled to suit the level of novelty, complexity, scale and risk on each project.

Not every element of this SE guide is relevant or should be applied on every project. Relatively simple track renewal, wharf resurfacing, bust stop replacement, overhead wiring (OHW), bus depot office refurbishment or minor junction remodelling projects may require a minimal level of SE application, whereas highly complex, novel network-wide programs such as bus fleet procurement may require SE application of most elements of this guide.

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The project-specific engineering team has the discretion to determine the scale and depth of SE effort to cost-effectively apply on the project. This may include parties responsible for delivering SE related services with input from AEOs and other contractors working on the project.

The information contained in this guide intends to support the achievement of the following AEO requirements – ENM1, ENM3, ENM4, ENM5, ENM6, ENM8, ENM9, ENM10, ENM11, ENM12, ENM13 and ENM14 provided in T MU MD 00009 ST *AEO Authorisation Requirements*.

3. Reference documents

The following documents are cited in the text. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies.

International standards

ISO/IEC/IEEE 29148:2011 Systems and software engineering - Life cycle processes - Requirements engineering

EN 50126-1:1999 Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic Requirements and Generic Process

EN 50128:2011 Railway Applications – Communication, signalling and processing system – Software for railway control and protection systems

Australian standards

AS/NZS ISO 9001 Quality Management Systems

AS/NZS ISO 31000 Risk management – Principles and guidelines

AS ISO 55001 Asset Management – Management Systems: Requirements

AS/NZS ISO/IEC/IEEE 15288:2015 Systems and software engineering - System life cycle processes

AS/RISSB 7722 EMC Management

Transport for NSW standards

T HR HF 00001 ST Human Factors Integration - Rolling Stock

T MU AM 01001 ST Life Cycle Costing

T MU AM 02001 ST Asset Information and Register Requirements

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

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T MU AM 06007 GU Guide to Requirements Definition and Analysis

T MU AM 06008 ST Operations Concept Definition

T MU AM 06009 ST Maintenance Concept Definition

T MU AM 06010 GU Business Requirements Specification

T MU HF 00001 ST Human Factors Integration - General Requirements

T MU HF 00001 GU AEO Guide to Human Factors Integration

T MU MD 00009 ST AEO Authorisation Requirements

T MU MD 20001 ST System Safety Standard for New or Altered Assets

TS 10504: 2013 AEO Guide to Engineering Management

Legislation

Rail Safety National Law

Work Health and Safety Act

Other reference documents

International Council on Systems Engineering 2015, INCOSE Systems Engineering Handbook: A guide for system life cycle processes and activities, fourth edition, Wiley

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

concept of operations verbal and graphic statement, in broad outline, of an organisation's assumptions or intent in regard to an operation or series of operations (ANSI/AIAA G-043-1992)

Note 1 The concept of operations frequently is embodied in long-range strategic plans and annual operational plans. In the latter case, the concept of operations in the plan covers a series of connected operations to be carried out simultaneously or in

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succession. The concept is designed to give an overall picture of the organisation operations. See also operational concept.

Note 2 The concept of operations provides the basis for bounding the operating space, system capabilities, interfaces and operating environment. (ISO/IEC/IEEE 29148)

ConOps concept of operations

CRN Country Rail Network

EMC electromagnetic compatibility

EMI electromagnetic interference

FFBD functional flow block diagram

FRACAS failure reporting, analysis and corrective action system

ICD interface control document

INCOSE International Council on Systems Engineering

IRS interface requirements specification

MBSE model based systems engineering

MCD maintenance concept definition

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

OCD operations concept definition

operational concept verbal and graphic statement of an organisation's assumptions or intent in regard to an operation or series of operations of a system or a related set of systems (ANSI/AIAA G-043-1992)

Note The operational concept is designed to give an overall picture of the operations using one or more specific systems, or set of related systems, in the organisation's operational environment from the users' and operators' perspective. See also concept of operations. (ISO/IEC/IEEE 29148)

OEM original equipment manufacturer

ONRSR Office of the National Rail Safety Regulator

OpEx operational expenditure

P50 estimate a cost estimate based on a 50% probability that the cost will not be exceeded

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

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project delivery within the context of this document, the TfNSW business unit responsible for managing the design and construction of the transport project. This includes integrated detailed planning, development, delivery and operations of transport services and projects. The output of all project delivery functions is the entry of the new or altered asset into operational service.

RACI responsible, accountable, consulted, informed

RAMS reliability, availability, maintainability, safety

RATM requirements allocation and traceability matrix

RIM rail infrastructure manager

RMS Roads and Maritime Services

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

SE systems engineering

SEMP systems engineering management plan

SI systems integration

SIP systems integration plan

SRS system requirements specification

SSRS subsystem requirements specification

STA State Transit Authority

stakeholder individual or organisation having a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectation (ISO 15288-2015)

TfNSW Transport for New South Wales

TfNSW transport asset transport assets vested in or owned, managed, controlled, commissioned or funded by TfNSW or a subsidiary NSW Government Agency

TfNSW Transport Network the transport system owned and operated by TfNSW or its operating agencies upon which TfNSW has power to exercise its functions as conferred by the *Transport Administration Act* or any other Act

Transport planning the business unit that focuses on evaluating, analysing and selecting a preferred candidate concept by providing substantial justification in the strategic business case.

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This function focuses on the business needs and requirements and therefore resides within the business organisation (that is, TfNSW) with some input from AEOs and relevant operator and maintainer agencies.

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

Note 1 to entry: The objective evidence needed for a validation is the result of a test or other form of determination such as performing alternative calculations or reviewing documents.

Note 2 to entry: The word "validated" is used to designate the corresponding status.

Note 3 to entry: The use conditions for validation can be real or simulated. (AS/NZS ISO 9000)

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

Note 1 to entry: The objective evidence needed for a verification can be the result of an inspection or of other forms of determination such as performing alternative calculations or reviewing documents.

Note 2 to entry: The activities carried out for verification are sometimes called a qualification process.

Note 3 to entry: The word verified is used to designate the corresponding status. (AS/NZS ISO 9000)

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.

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

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

SE 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, functional, non-functional and safety requirements. 'Needs' are seen as defining the problem domain, while a 'definitive system configuration' is viewed as the solution domain and SE manages the synthesis from the former to the latter.

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

The SE 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

The 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
- the inclusion and support of operational integration will ensure that the system functions in an integrated way and assist in removing the 'silos'
- SE considers and provides an approach to minimise or eliminate electromagnetic compatibility (EMC) issues
- SE considers how a reliable, available, maintainable and safe system can be achieved

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- SE approach provides justified confidence that the system can be accepted
- SE aims to ensure the humans in the system are considered through human factors integration so that the system designed is safe, efficient and effective during operations and maintenance
- SE approach supports the planning and design to achieve stated function and performance for effective operational readiness and entry-into-service
- 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
- SE provides an approach to understand emerging properties of integrated systems

5.3. Possible outcomes of not using systems engineering

A system can fail to meet its intended purposes in many ways and the 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 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 (operational expenditure) costs and effort are higher than expected
- system is not operable, maintainable or usable by staff and customers in a safe, cost-effective manner
- loss of professional and political reputation and withholding of future funding

5.4. Practical application of systems engineering

The following 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, verification and validation)
- 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

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- 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
- integrate and collaborate with project management, procurement, safety, risk and financial management areas

5.5. Scaling and tailoring SE effort

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.

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.

The SE effort is determined based on the novelty and complexity of the project. Novelty refers to systems, assets, processes and support arrangements not used previously on the TfNSW Transport Network whereas complexity refers to the following:

- 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
- process complexity

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, scaling and risk is provided in the project example table in Appendix B.

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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 TfNSW Transport Network. SE as a methodology fits within the following broader TfNSW business enterprise context:

- Quality management framework (based on ISO 9001)
- Enterprise asset management framework (based on AS ISO 55001:2014 *Asset Management – Management Systems: Requirements*)
- Enterprise risk management (based on AS/NZS ISO 31000 *Risk management – Principles and guidelines*)

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. Refer to T MU AM 01001 ST *Life Cycle Costing* for more information on financial management and how whole-of-life cost is considered throughout the life cycle.

7. System overview

The multi-modal 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.

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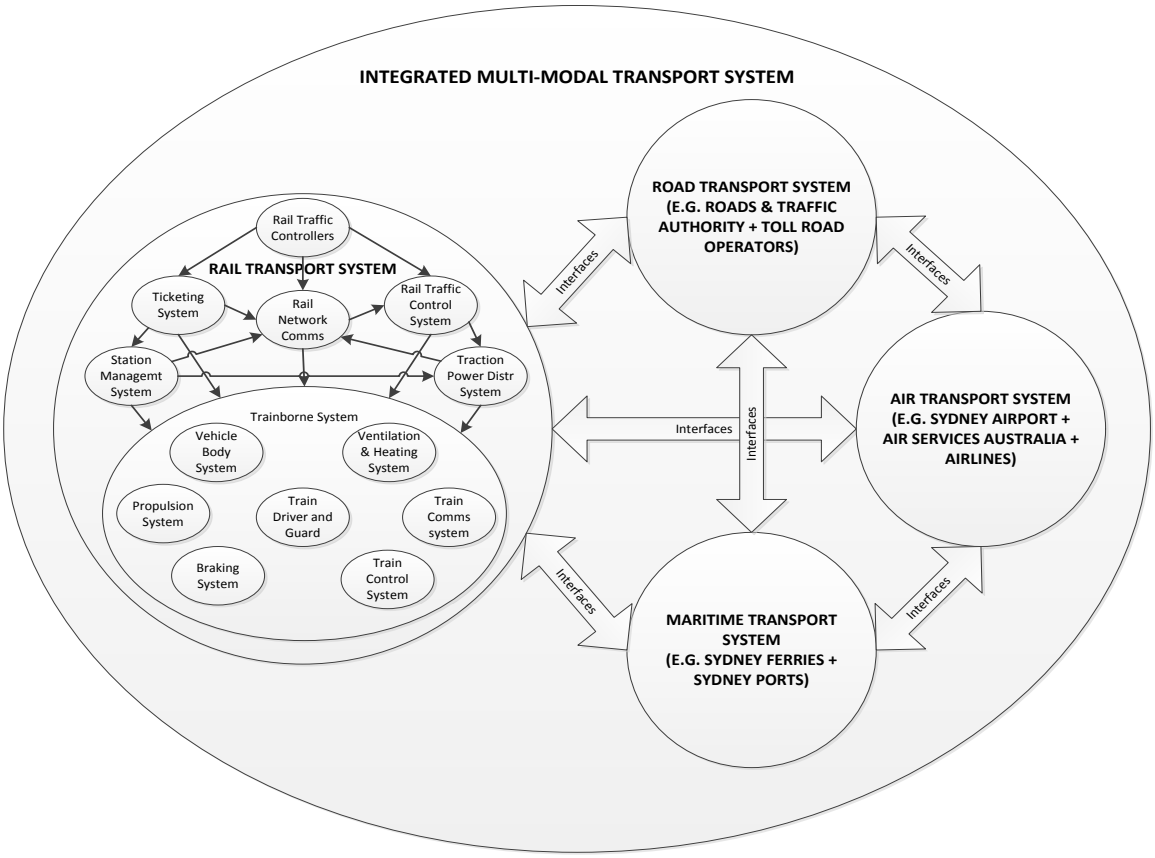

Figure 1 - Integrated multi-mode transport system of systems

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. However, light rail is a combination of road and rail transport system. At a higher level, the transport system sits within the broader NSW infrastructure context.

A railway system 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.

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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.

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.

Stakeholder perspectives may include the planner, designer, implementer, operator, maintainer and the passenger. These perspectives may be represented as a 'systems engineer' or a 'requirements engineer' on a project who is responsible for writing the business, system and subsystem requirements for the project. This list is not exhaustive and there may be additional stakeholder perspectives. Figure 2 illustrates the multiple viewpoint requirements conceptually.

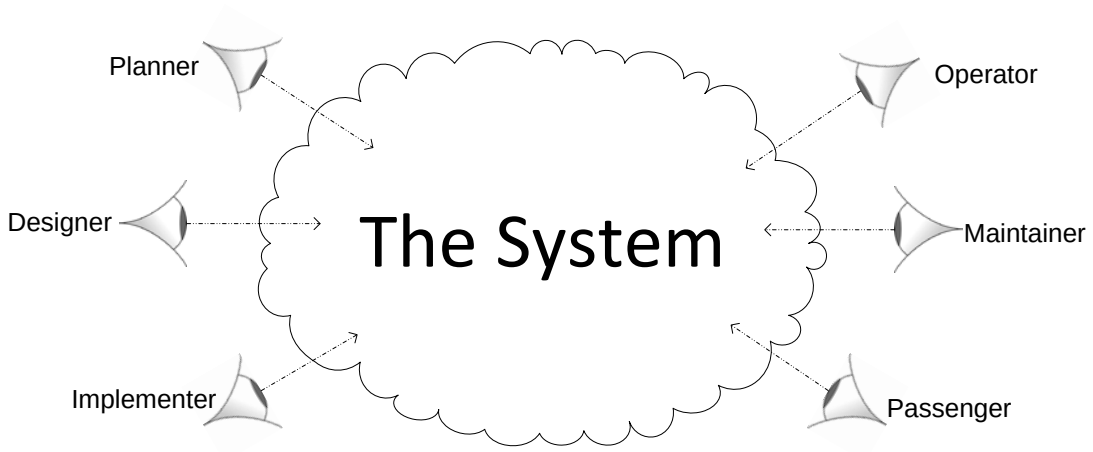

Figure 2 - System stakeholder viewpoints

7.1.1. Planner viewpoint

The planner represents inputs from the following stakeholders:

- The operator and maintainer for delivering timetable services and maintaining the transport assets.
- The business function responsible for publishing and maintaining transport standards. Transport standards and guides may potentially impact TfNSW Transport Network asset integrity.
- Assurance of network safety through regulatory requirements, such as the Office of the National Rail Safety Regulator (ONRSR).
- Other authorities and local government, for interfaces and impacts on own assets.
- Various functional areas responsible for the following:

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- Developing service level agreements with operating agencies.
- Analysing customers' needs into requirements.
- The long term transport needs of NSW and developing options based on analysis of customer needs and freight policy. The outputs focus around the strategic business case.
- Development of the selected option and agrees the outputs and requirements that the business wants to achieve from investment. The outputs focus around the final business case and agreed business requirement specification (BRS).
- Provide integrated end-to-end planning, development, delivery and operations of transport services and projects.

The planner is involved in the ‘concept', 'specify’ and 'procure' phases of the life cycle (defined in Section 8.2), 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 translating the TfNSW enterprise goals and outcomes to determine the operational and maintenance needs, which are then used to develop the business requirements. The planner also focuses on the system's functional, operational and performance requirements.

7.1.2. Designer viewpoint

The designer’s viewpoint is represented by the following:

- operator and maintainer in some cases (for example, for minor capital works)
- design consultancies as AEOs
- various functional areas responsible for the following:
  - managing assurance up to approved for construction (AFC) before CM gate 3
  - managing the design of the transport project up until construction or production, or both

The designer views the system with an intent to translate the business requirements into system requirements 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 to TfNSW project delivery organisations.

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7.1.3. Implementer viewpoint

The implementer's viewpoint is represented by the following:

- The business unit responsible for managing construction, integration and testing, verification and validation, and post-AFC assurance up to system acceptance. The output of this function is the entry into operational service.
- Construction and testing companies as AEOs.
- For rail project, the operator and maintainer as rail infrastructure manager (RIM) or rail service operator (RSO) responsible for providing infrastructure access to AEOs.

The implementer views the system with an intent to translate the AFC 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.

7.1.4. Operator and maintainer viewpoint

The viewpoint of an operator and maintainer is represented by the transport agencies and contracted operators and maintainers.

While this guide is developed initially to apply directly to rail transport, the operator and maintainer 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, maintainable and sustainable over the systems operational lifetime.

7.1.5. Passenger viewpoint

The passenger's viewpoint is represented by the entity responsible for conducting, collecting, analysing and documenting the needs of the people who use the transport service to commute to work, school, university, airport or any other desired destination. This viewpoint is captured in the form of customer needs and categorised under a defined set of customer value propositions such as convenience, safety, security, comfort, accessibility and timeliness to name a few. These customer needs should then be translated into formal statements as business requirements on projects and then validated once the system is developed. These business requirements could also be represented in the form of use cases to capture the specific tasks and activities that passengers undergo when using the transport service. The development of use cases assists in eliciting system requirements to describe what the new or altered system will do to achieve the parent business requirement.

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The passenger viewpoint should be considered at the outset of the project to ensure a customer centric approach and that the right system is being delivered for the public of NSW.

For more information on customer and business requirements, refer to T MU AM 06010 GU *Business Requirements Specification*.

7.2. Requirements hierarchy and structure

Using a multidisciplinary approach, SE determines the following outputs at the early stages of the system life cycle:

- 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 to solutions as represented in Figure 3. This starts with identifying the enterprise need or goals and supporting the capability concept of operations (ConOps), then defining the concept activities in an operations concept definition (OCD) document and maintenance concept definition (MCD) document. In addition to these source documents, there are other informing artefacts produced on a project to support the business requirements specification (BRS) such as hazard log, assumptions, dependencies and constraints (ADC) register, value for money (VfM) studies, and issues register to name a few. 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 project delivery business unit will use the BRS as a basis to facilitate the design and construction of the new or altered asset.

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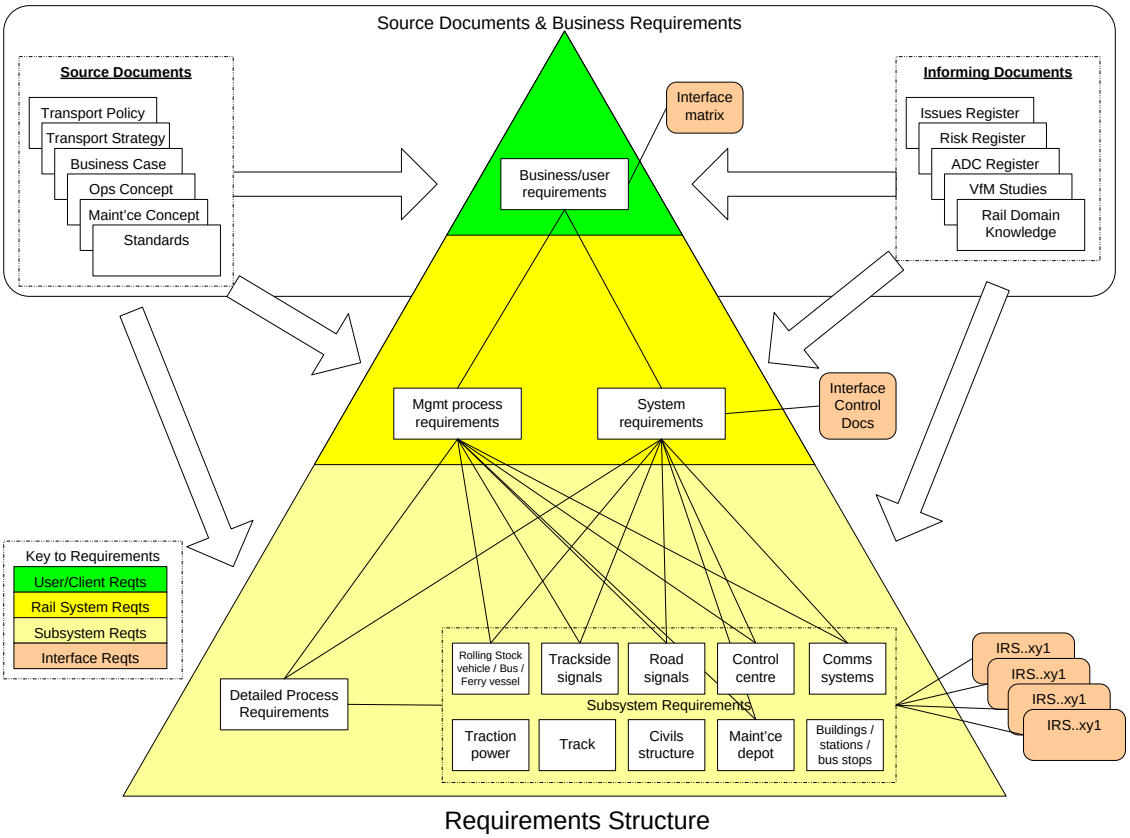

Figure 3 - Requirements hierarchy and structure

The project delivery unit establishes a project team including technical advisors (drawn from industry AEOs) to develop the concept design up to a reference design with an associated system requirements specification (SRS). This forms the basis of a tender.

Some organisations may choose to define management process requirements, and manage the assurance that these process requirements are successfully implemented on the project.

T MU AM 06004 ST *Requirements Schema* does not make provision for management process requirements; therefore AEOs may be required to manage them as part of overall assurance. The reason for this is to minimise prescribing 'how' the AEO supply chain should deliver the outcomes.

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 and contractual requirements.

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7.3. Concept of operations

The ConOps is a high level document developed at an enterprise level in the demand and need phase of the system life cycle. The ConOps refers to how enterprise management intends to operate the organisation with the new system in place to satisfy the organisation's goals and objectives as documented in the future transport strategy.

The ConOps document serves as a basis for the organisation to direct the overall characteristics of the future business and systems required to operate the business.

The ConOps document is not a requirements document and only describes how TfNSW will operate to execute the strategy; however it provides an overarching high-level view of the organisation. The ConOps is used to derive a set of business and customer needs to inform the OCD and MCD.

7.4. Operations concept

The 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 strategic business case.

The OCD requirements are stated in T MU AM 06006 ST.

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.

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

An OCD may not be necessary to be produced for every project type, 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.

Where a project significantly affects the operations, an OCD should be developed even if the project is simple. 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.

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; however it 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.

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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 OCD 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.

For non-rail transport projects, upgrading or refurbishing the propulsion system on a bus or ferry fleet may not require an OCD but a timetable update will require an OCD as it directly affects operations.

OCD requirements are defined in detail in T MU AM 06008 ST *Operations Concept Definition* and the guidance information for developing an OCD is provided in T MU AM 06008 GU *Operations Concept Definition*.

A sample OCD context diagram for a railway system is shown in Appendix D.

7.5. Maintenance concept

The 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.

The MCD requirements are stated in T MU AM 06006 ST.

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

MCD is typically 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 MCD.

Where a project significantly affects the maintenance, an MCD should be developed even if the project is simple. The project should consult with relevant stakeholders to determine the need for an MCD.

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

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result in better prediction of potential failures, and may lead to reduced response times, lower mean time to repair, and higher system availability.

The strategic business case and its associated funding are supported by the MCD and they 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. In some cases, the OCD and MCD may be combined into a single document. The operations and maintenance concepts can be combined where practicable, as they are closely related, if the maintainer is also the operator of the system.

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) for heavy rail or 'out of service' bus booking, 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.

The maintenance concept should be written in accordance to T MU AM 06009 ST *Maintenance Concept Definition*.

7.6. Functional architecture

The functional architecture requirements are stated in T MU AM 06006 ST.

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. The logical or functional description changes slowly while the physical description changes much faster, particularly as the pace of technological change quickens. De-linking of functions from physical asset groups permits innovative solutions to be offered by existing and new product suppliers.

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An example of this is a ‘movement authority’ that is currently issued via 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 permitted 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 than novel solutions 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 and control and communications systems with significant embedded software functionality.

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.

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 Architecture (TNA) model.

Figure 4 shows an example of a functional architecture sample fragment from the TNA model using TRAK. The diagram ID is [TRAK_SV-05-MU-MD] which means it adopts the TRAK solution viewpoint, multi-modal and multi-disciplined showing a set of signalling functions that realise a set of concept activities for heavy rail and light rail vehicles.

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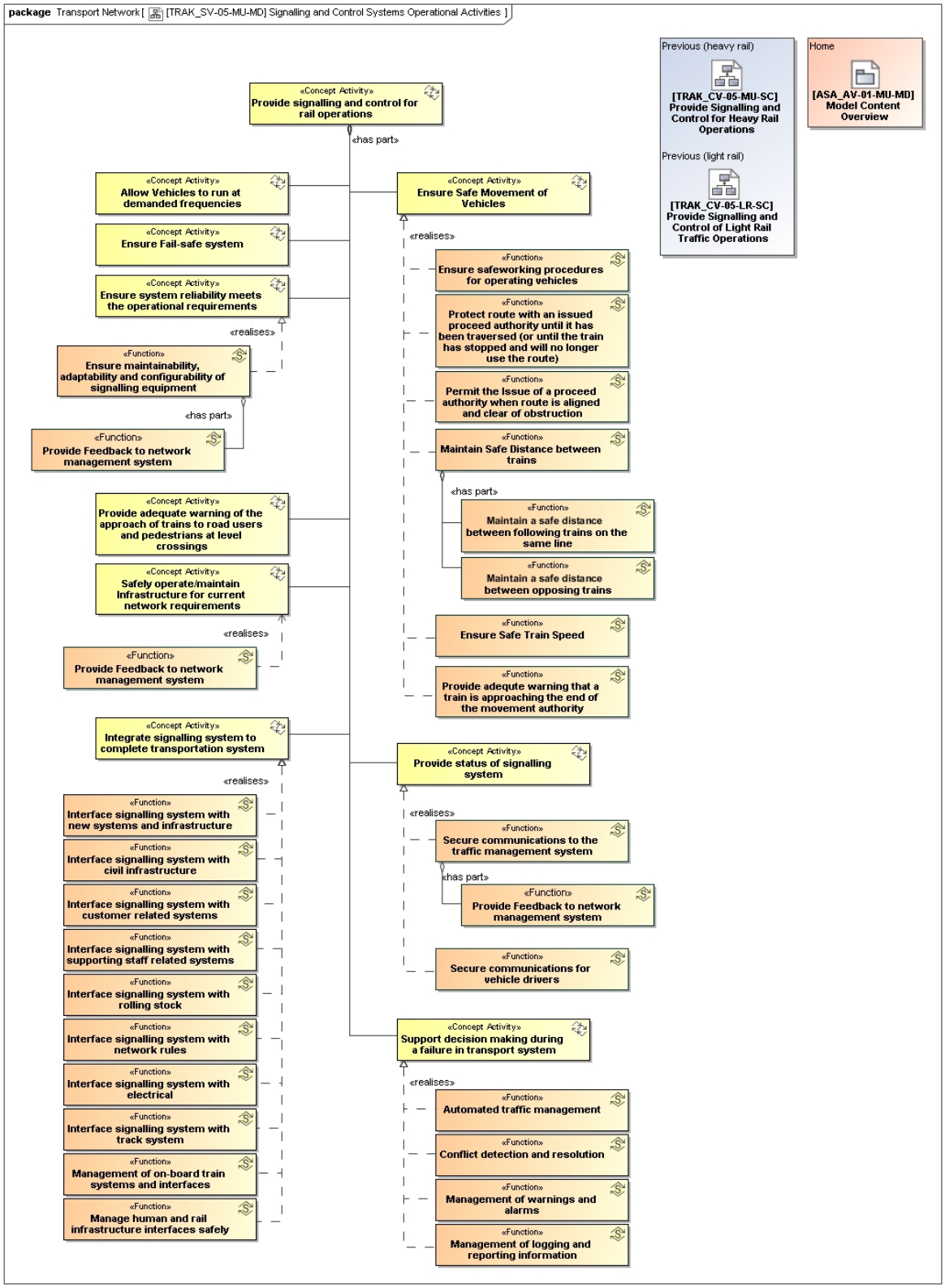

Figure 4 - Functional architecture diagram (sample fragment)

7.7. Physical solution architecture

The physical solution architecture requirements are stated in Section 7.3.2 of T MU AM 06006 ST.

In some cases, the use of the term asset breakdown structure (ABS) is used in documents and projects in TfNSW to mean system breakdown structure (SBS).

The ABS is referred as SBS in this guide and the standard (T MU AM 06006 ST), it supports.

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.

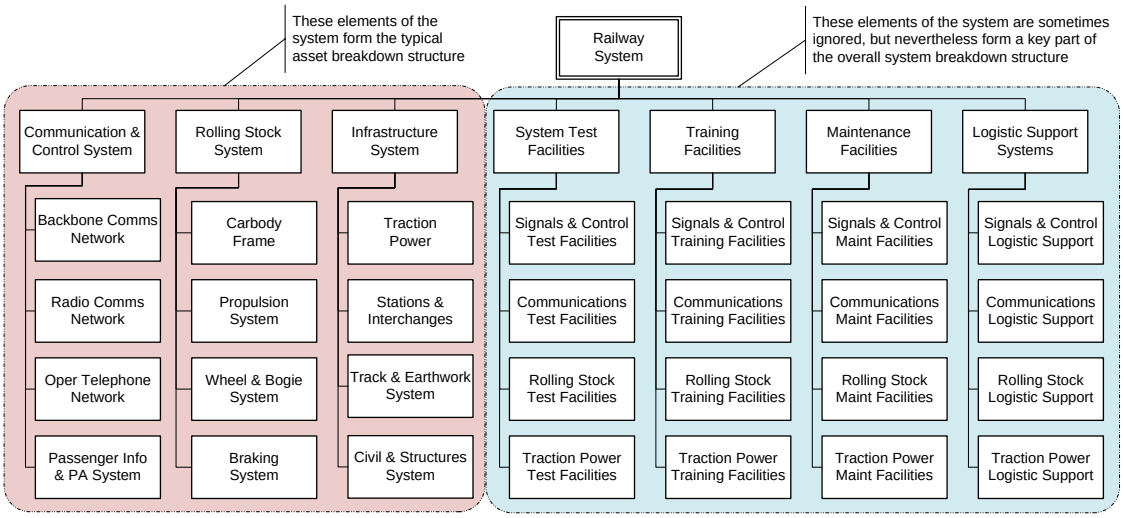

Figure 5 - Physical System Breakdown Structure (sample fragment)

A generic asset classification scheme, which serves as the SBS for TfNSW transport assets, is shown in Appendix E. This classification scheme is described in more detail in T MU AM 02001 ST *Asset Information and Register Requirements*.

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; it 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.

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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.

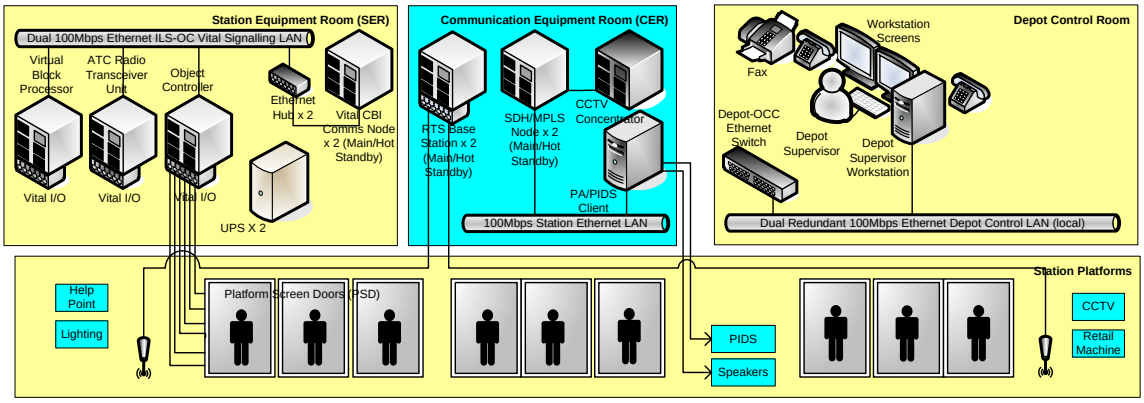

Figure 6 - Physical system block diagram (sample fragment)

Practical railway examples of physical architecture 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

7.8. Geographic deployment architecture

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.

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Figure 7 shows a sample fragment of a geographical architecture diagram for a rapid transit railway.

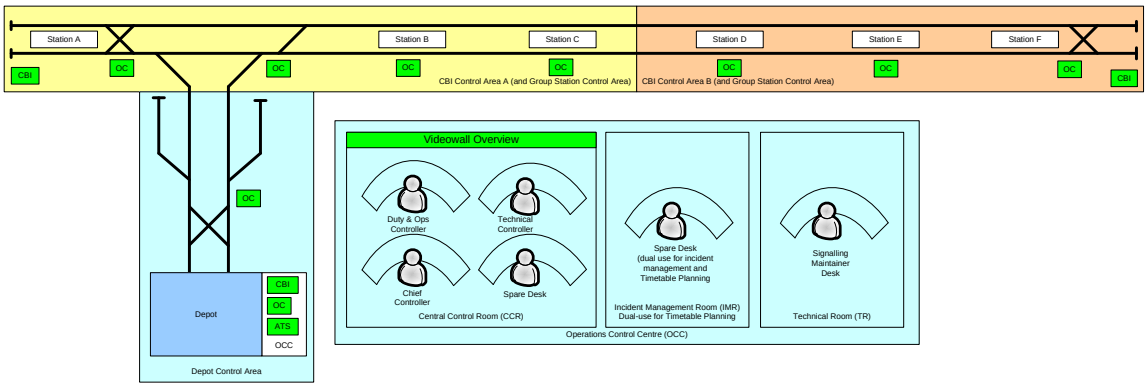

Figure 7 - Geographic architecture diagram (sample fragment)

Practical railway examples of geographic architecture that indicate the geographic layout and disposition of physical assets and systems include, but are not limited to, 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

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7.9. Interface architecture

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

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

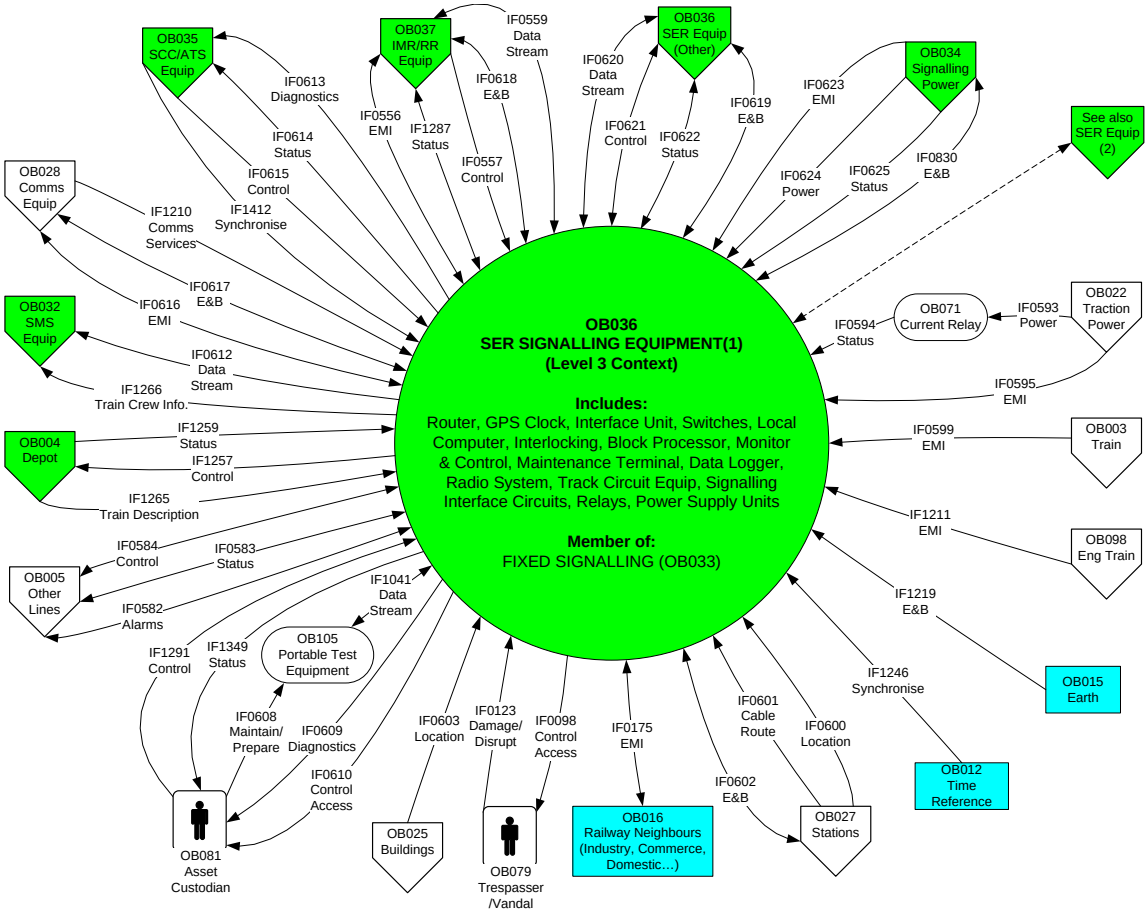

Figure 8 - System context/interface diagram (sample fragment)

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.

7.10. Interim system migration states

On high-complexity programs and portfolios of projects such as Sydney Metro, automatic train protection (ATP), power supply upgrade (PSU) or fleet replacement, 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 7.6, Section 7.7 and Section 7.8.

8. System life cycle description

T MU AM 06006 ST mandates deploying 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 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.

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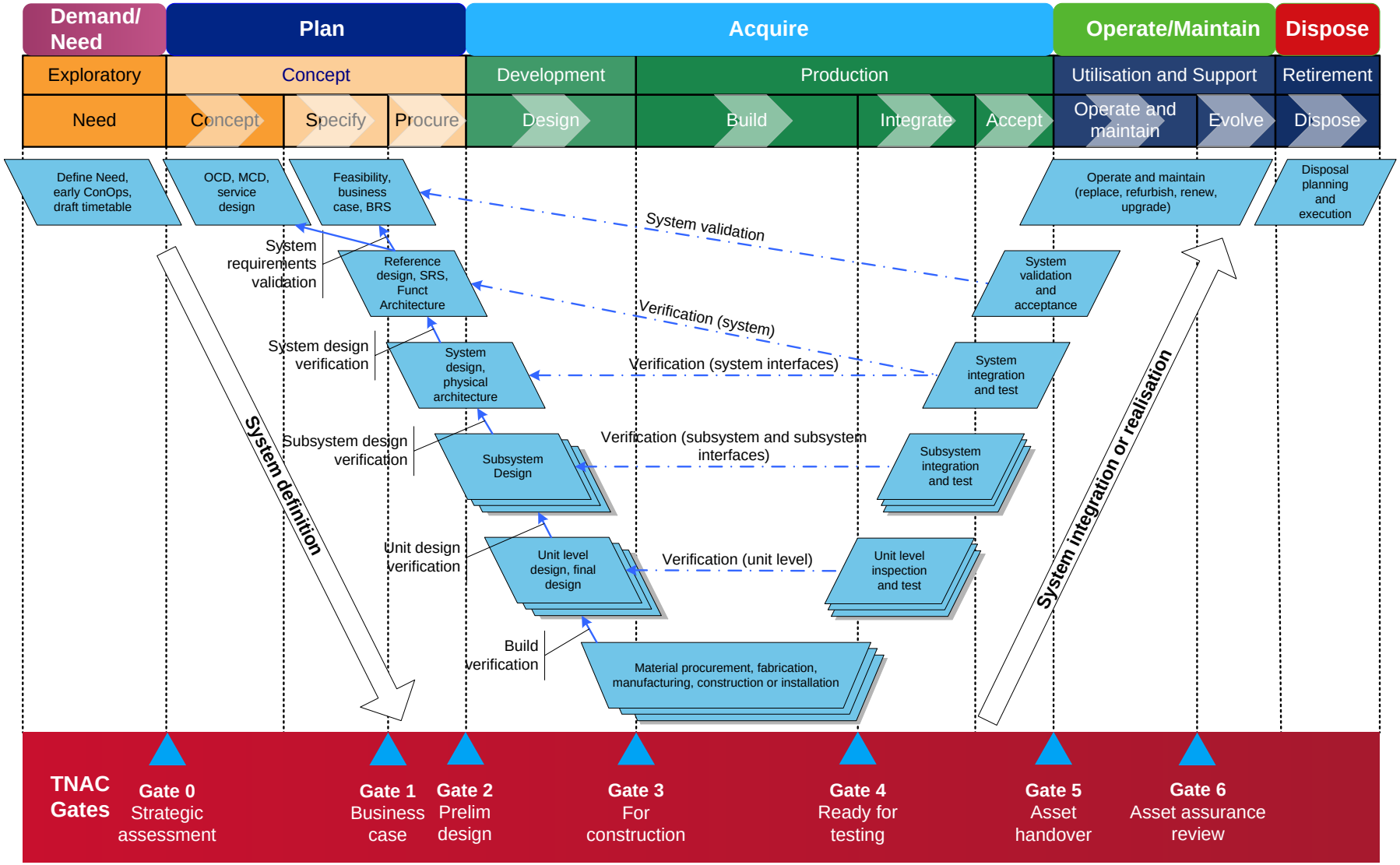

Figure 9 - TfNSW system V life cycle model with configuration gates

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The V model is aligned to the asset management life cycle stages defined in the key TfNSW Transport Network Assurance Committee (TNAC) gateways. Figure 10 shows the relationship between the asset life cycle stages and CM gateways. For more information on CM gate submission and minimum requirements for each gate, refer to T MU AM 04001 PL *TfNSW Configuration Management Plan*.

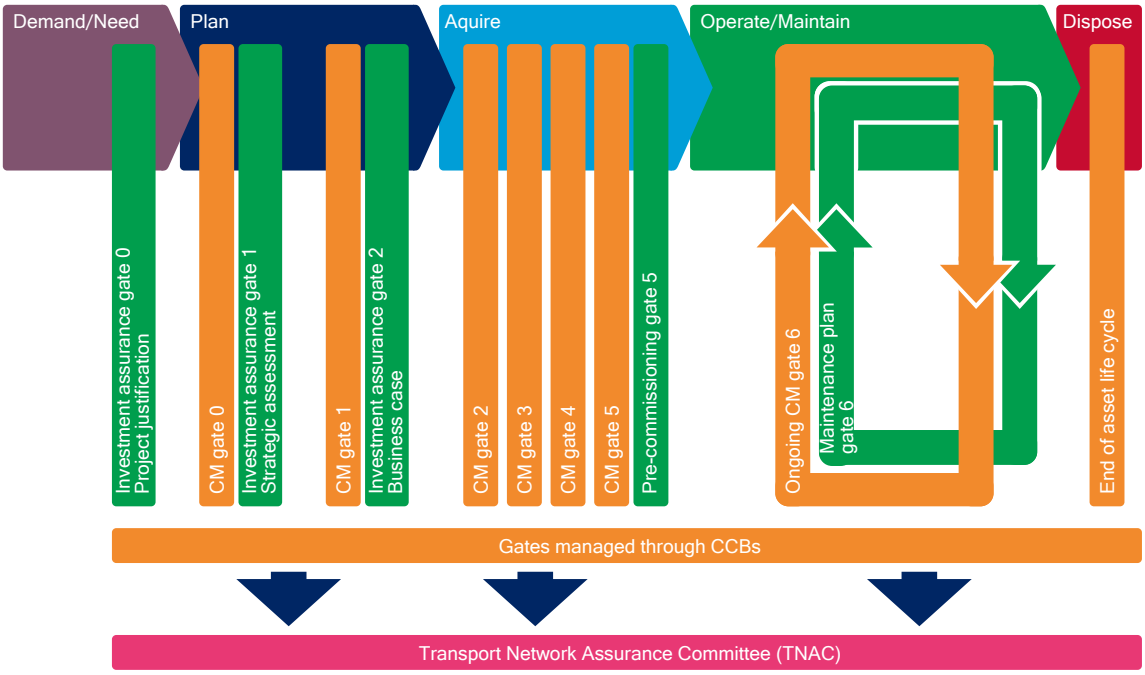

Figure 10 - TfNSW asset life cycle stages and configuration gateways

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 can be characterised by a number of V models over the full system life cycle, as shown in Figure 11.

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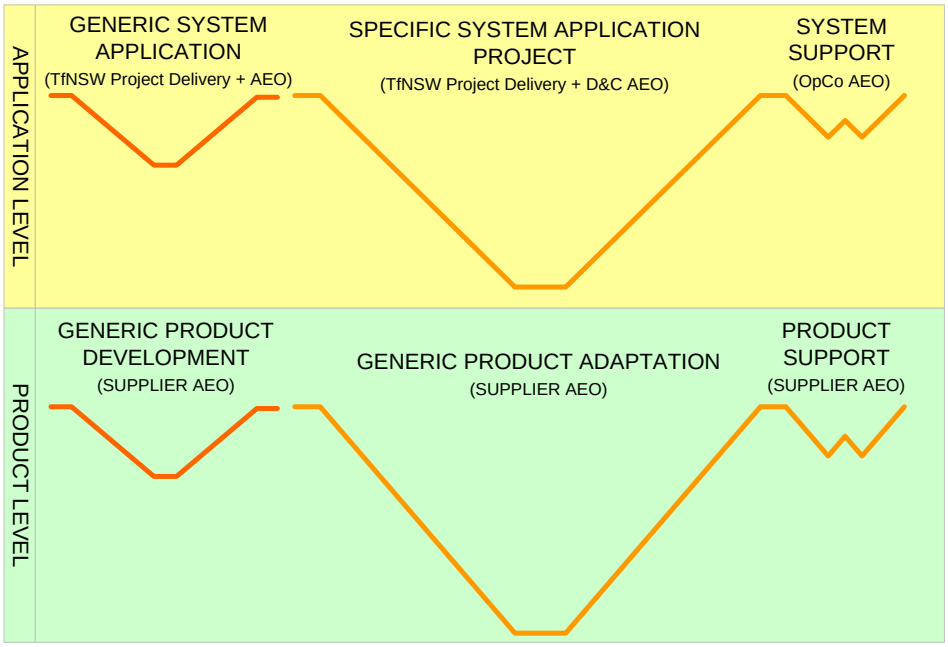

Figure 11 - Composite SE life cycle models

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 Figure 19 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 to develop a proof of concept and standard generic approach to application of new technology at a system level (for example, Opal ticketing system on all public transport services and eventually trialling contactless EFTPOS card services).

The specific system application life cycle applies to specific system implementation projects planned by the planners, and delivered under contracts by the project delivery group.

The system support life cycle applies to mid-life upgrades by the operator and maintainer 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 original equipment manufacturing (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

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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 Figure 19 of Appendix C.

8.2. System life cycle phases

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 8.2.1 through to Section 8.2.7.

8.2.1. Exploratory phase

The exploratory phase maps to the demand and need stage in the TfNSW asset life cycle. The exploratory phase may be referred to as the 'need' phase.

The key responsible parties include the following functional areas:

- entity responsible for analysing customers' needs into requirements
- strategic transport planning
- entity responsible for developing service level agreements with operating agencies

The operator and maintainer or 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* or *Work Health and Safety Act*.

The key activities and deliverables include transport needs analysis, development of multiple service options, high level business needs and an early ConOps.

8.2.2. Concept phase

The concept phase maps to the 'plan' stage (concept, specify and procure) in the TfNSW asset life cycle.

The key responsible parties include the following functional areas:

- strategic transport planners
- project delivery group

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- AEOs contracted to provide technical advice and operator and maintainer providing services as an AEO under contract to TfNSW

The key activities and deliverables include high-level transport performance modelling to validate the following:

- early OCD and MCD development
- preferred option concept design
- timetable
- benefits realisation management plan
- business case
- tender documentation
- systems engineering management plan (SEMP)
- early operational readiness and change management planning
- verification and validation (V&V) plan
- P50/P90 risk-assessed cost estimates
- early consideration of human factors integration (HFI)
- BRS
- draft SRS
- approved business case
- setting of RAM and other key system performance targets

8.2.3. Development phase

The development phase maps to the 'acquire' stage (design) in the TfNSW asset life cycle.

The key responsible parties include, project delivery group within TfNSW and AEOs contracted to provide design services to TfNSW in this stage.

The key activities and deliverables include OCD and MCD refinement, final SRS, development of detailed designs, product specifications, process specifications, material specifications, V&V strategies, consideration of HFI and RAM performance considered, and finalised operational readiness and change management plans.

8.2.4. Production phase

The production phase maps to the ‘acquire stage’ (build, integrate, and accept) in the TfNSW asset life cycle.

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The key responsible parties include, project delivery group within TfNSW, AEOs contracted to provide the services of supply, manufacturing or fabrication, site installation, integration, testing and commissioning to TfNSW, and may involve the operator and maintainer.

The key activities and deliverables include development of detailed designs, bills of materials, product specifications, procuring or fabricating products or equipment, installation or construction and integration on site, subsystem and system testing, commissioning, operational readiness demonstration and handover to the TfNSW asset owner and operator and maintainer.

8.2.5. Utilisation phase

The utilisation phase maps to the 'operate and maintain' stage of the TfNSW asset life cycle.

The key responsible parties include the transport agencies, contracted operator and maintainer and other transport operators.

The key activities and deliverables include asset acceptance from the project delivery organisation, operational safety argument, ongoing operation of these assets, and periodic major maintenance or minor capital projects to restore system performance capability to the original design intent.

8.2.6. Support phase

The support stage maps to ‘operate and maintain’ stage of the TfNSW asset life cycle, and runs concurrently with the utilisation stage.

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

The key activities and deliverables include asset acceptance from the project delivery organisation, asset condition assessments, preparing asset maintenance plans, performing failure reporting, analysis and corrective action system (FRACAS), carrying out general asset maintenance and logistic support activities (including mid-life upgrades) against these plans.

8.2.7. Retirement phase

The retirement phase maps to the 'dispose' stage of the TfNSW asset life cycle.

The 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.

The key activities and deliverables include asset condition assessments to support any decisions to retire systems that have reached the end of their design life, or changes in asset utilisation.

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The reasons why the asset or system may be retired are as follows:

- The system was designed with the intent to dispose after its expected life and is no longer useable or supportable, or both. This option suggests that the system was designed with the intent to 'dispose' it.
- Subsystems or assemblies of the system were designed with the intent to last less than the expected life of the whole system and therefore need to be retired to make way for a new or altered subsystem. This option suggests that the system was designed with the intent to 'refurbish' or 'remanufacture' the system.
- The system still meets the operational requirements but the business need for the system may have changed resulting in retirement of assemblies or components to satisfy the new business needs or retiring the system as a whole.
- System may be damaged and is beyond repairable.

Once the reasons for potential retirement have been identified, each can be examined for potential retirement methods such as:

- Sell the asset as a second-hand item.
- Re-used as a training aid.
- Destroyed and disposed as waste.
- Disassembled and working subsystems used on the new system. This also includes items that need to be scrapped, recycled or both.
- Re-purposed (for example, heritage building becoming museums).

Once the retirement methods have been identified, the operator and maintainer of the retired asset may identify any design issues that may arise for the new or altered system such as:

- avoidance of the use of hazardous or toxic materials
- observe recycling regulations
- environmental impact
- cost of; disposal, destruction, uninstallation or refurbishment
- transportation cost for disposal
- need for specialised personnel and equipment required for disposal
- availability of design data and drawings to support disposal at the end of life of asset

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9. Systems engineering organisation structure

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.

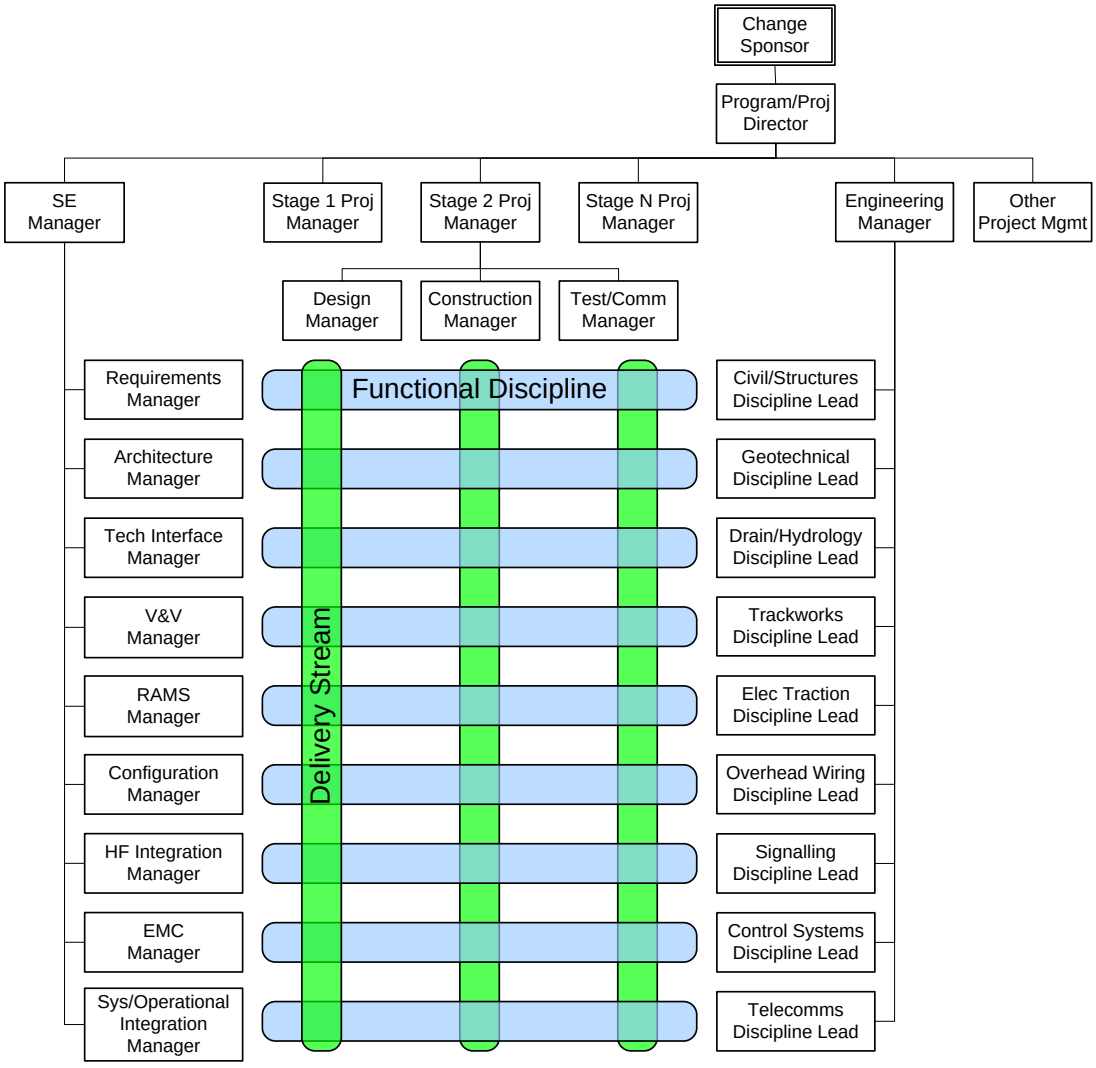

Figure 12 - Matrix project organisation (sample fragment)

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).

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.

The following are some of the advantages of matrix organisational structure:

- resource coordination (leads focus on area of expertise, either engineering or PM)

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- 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 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

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. An 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.

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 such as ETCS-L2, SE responsibilities listed in Table 1, represents the minimum SE roles and responsibilities.

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Table 1 – Systems engineering roles and responsibilities

Role	Responsibilities
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
Operational integration manager	• establish and maintain OCD and MCD documents • prepare the operational readiness plan • coordinate and direct the training, competency and learning plan • develop, and direct implementation of the change management plan • lead and direct stakeholder management activities

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Role	Responsibilities
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 • communicate and coordinate activities with other SE management activities
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 specifications (IRSs) • 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 context and use of HF and ergonomic requirements • identify users and perform HF assurance activities • plan HF activities, establishing and maintaining a human factors integration plan (HFIP) as required • identify, implement and use HF tools as required to support design solutions and HF analysis • execute HF tasks and activities related to the engineering effort • evaluate design from a HF perspective • evaluate HF solutions • 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

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Role	Responsibilities
EMC manager or 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

Project organisations are scaled and structured according to the scope, scale and complexity of the system (or system or systems) to be delivered. The effort of systems engineering should be scaled and tailored 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 Future Transport Strategy group.
- Program integration management organisations include the ATP, PSU, 2018 TT, and DTRS programs, which each consist of multiple projects to deliver specific subsystems or geographic scopes.
- Product development organisations include OEM that provides generic products that are approved, selected and procured for specific application.
- Project development organisations include TfNSW project delivery group, and (to some extent) relevant operator and maintainer agencies such as Sydney Trains, Roads and Maritime Services (RMS), NSW Light Rail, NSW Trains and State Transit Authority (STA) who develop projects to the point where an SRS and a costed reference design are issued to tender.
- Project delivery organisations such as TfNSW project delivery group and supply chain AEOs who deliver the scope of works in terms of detailed designs, procurement, manufacturing or fabricating, installation, integration, testing, commissioning, acceptance and hand over to the asset operator.

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- Operator and maintainer organisations include the transport agencies and contracted operators and maintainers. 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

The levels of responsibility and engagement of key organisational roles should be mapped to SE and related processes in a RACI (responsible, accountable, consulted, informed) 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 and high novelty program of works.

KEY:
R = Responsible
A = Accountable
C = Consulted
I = Informed

		Stakeholders					Project Leadership					SE & Related Management											Contractor		
		PROJECT ROLES																							
		Change Sponsor	Acceptance Client	Program/Project Delivery	OpCo (Operators & Maintainers)	External (Council, Utilities)	Project Director	System Safety Manager(s)	Document/Data Manager	Operational Integration Manager	Engineering Manager	Systems Engineering Manager	Requirements Manager	Human Factors Integration Manager	Technical Interface Manager	RAM Manager	V&V Manager	Design Manager	Construction Manager	Test & Commissioning Manager	Design Consultants	Product Suppliers/Manufacturers	Construction Contractors		
SYSTEMS ENGINEERING & RELATED MANAGEMENT PROCESSES	Operation & Maintenance Analysis	I	I		C		A		C	C	C		R	C	C		R								
	Requirements Management	I	I		C		A		C	C			R	R	C	C	C	C	C	C					
	System Modelling & Analysis						A			C			R	C	I	C	C	C	C	C					
	System Architecture Management						A			C			R	C		C	C			C					
	Software/Data Development						A			C			R	C	C	C	C			C					
	Design Management						A			C		R		C	C	C	C	C	R	C			R		
	Manufacturing Management						A			C		R						C		C				R	
	Construction Management						A			C		R						C		R					R
	Systems Integration Management	I	I				A			C	C				C	C		C		R					
	Inspection & Test Management						A		C	C		R		C	C	C	C	C		R	R				
	Verification & Validation Management						A		C	C			R	C	C	C	C	R		C					
	Compliance Management						A		C	C	I		R	C				R		C					
	Performance Demonstration						A			C	I		R	C	C		C	C			R				
	Commissioning Management	I	I		C		A		C	C	C	R				C		C			R				
	Acceptance Management	I	I		R		A		C	C	C		R	C	C		C	C			R				
	Systems Engineering Management						A			C			R		I										
	Competence Management				C		A		C	C	R		R		C			C							
	Training & Development Management				C		A			C	R		R		C										
	Systems Assurance/Audit	I	I				A		C	C			R	C	C			R							
	Configuration Management	I	I		I		A		C	C		R	C			C				C					
	Engineering Change Management	I	I				A		C	C		R				C				C					
	Document & Data Management	I	I	I	I		A	C	C	R	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
	Technical Interface Management						A		C	C			R	C	C	R									
	Technical Issues Management						A		C	C		R		C			C								
	RAM Management	I	I				A		C	C			R	C	C		R								
	System Safety Management	I	I		I		A		R	C	C		R	C	C	C	C								
	Human Factors Integration				C		A		C	C	C		R	C	R	C	C		R				R		
	EMC Management						A		C	C			R	C		C	C								
	Lifecycle Support Analysis	I	I		C		A			C	C		R	C			R								

Figure 13 - Systems engineering RACI matrix for a high complexity project or program

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10. Systems engineering shared information

The requirement for SE related shared information is stated in T MU AM 06006 ST.

Over the system life cycle, during planning stage and acquisition stage, 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 the other processes that uses the shared information.

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 and 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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KEY:
O = "owns" info
U = "uses" info

SHARED INFORMATION	Operation & Maintenance Analysis	Requirements Management	System Modelling & Analysis	System Architecture Management	Software/Data Management	Design Management	Manufacturing Management	Installation Management	Systems Integration Management	Inspection & Test Management	Verification & Validation Management	Commissioning Management	Systems Engineering Management	Competence Management	Systems Assurance Management	Configuration Management	Engineering Change Management	Document & Data Management	Technical Interface Management	Technical Issues Management	System Safety Management	RAM Management	Human Factors Integration	EMC Management	Lifecycle Support Analysis
	SYSTEMS ENGINEERING & RELATED PROCESSES																								
Requirements Source Baseline	U	O	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Standards Baseline	U	U	U	U	U	U	U	U	U	U	U	U	O	U	U	U	U	U	U	U	U	U	U	U	U
Requirements Database		O	U	U	U	U					U	U			U	U			U		U	U	U	U	
Functional Architecture				O	U	U										U					U	U	U	U	
Physical Architecture				O	U	U			U							U			U		U	U	U	U	
Bill of Materials (BOM)						O	U	U																	
Engineering Change Register	U	U	U	U	U	U	U	U								U	O		U	U		U			U
Configuration Database		U	U	U	U	U			U							O	U		U			U		U	U
Design Models/Information Register	U	U	O	O	U	O			U		U					U	U		U		U	U	U	U	U
Document/Data Register						U										U		O							
EMC Threat Matrix/Risk Register						U			U		U											U		O	
Engineering Comments Register	U				U	O			O		U								U	U	U	U	U	U	
Verification Error Log						U			U		O								U		U	U		U	
Hazard Log/Safety Risk Register						U					U				U	U					U	O	U		U
Human Factors Issues Log/Register	U	U				U			U	U	U		U	U					U	U	U	U	O		U
Systems Integration Schedule									O		U								U						
Technical Interface Register		U	U	U	U	U			U		U					U			O		U	U	U	U	
Interface Control Docs		U	U	U	U	U			U	U	U		U			U	U		O	U		U	U	U	
Technical Issues Register	U	U	U	U	U	U			U		U	U				U			U	O	U	U	U	U	
Technical Maintenance Plans	O																				U				U
Manufacturing Database							O										U			U	U	U		U	U
Non-Compliance Register (audit)	U	U	U	U	U	U	U	U	U	U	U	U	U	U	O	U	U	U	U	U	U	U	U	U	
Roles/Responsibilities Chart													O	U	U							U			
System RAM Models (RBD)	U	U	U	U	U	U					U				U	U	U		U	U	O	U	U	U	U
System Safety Models (FTA,GSN)	U	U	U	U	U	U					U				U	U	U		U	U	U	O	U	U	
Product RAM Data	U		U			U	U								U					U	O				U
Product/Asset Breakdown	U		U	U		O	U	U	U	U	U					U			U		U	U		U	U
Technical Risk Register		U											U						U	O	U	U	U	U	
Project Deliverables Schedule						U	U	U	U	U			O			U	U	U							
Inspection & Test Logs	U							U	U	O	U	U			U	U			U		U	U		U	
Operational Integration Plans	U	U							O		U	U			U	U		U				U	U		U
Verification & Validation Evidence	U							U	U	U	O	U			U	U			U		U	U		U	
Competency & Training Register	U													O								U	U		

Figure 14 - Shared information resources and SE related processes

11. Systems engineering management plan

T MU AM 06006 ST mandates that a systems engineering management plan (SEMP) be produced when an assurance argument based on a judgement of significance (JOS) identifies the need for a SEMP.

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

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11.1. Need for a SEMP

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.

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

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 address 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 Amps to 6000 Amps, or increase passenger capacity in station concourse from 1000 to 2000.

11.3. Systems engineering deliverables

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

- BRS and SRS complete and signed by sponsor (can be in the form of a RATM/RVTM)
- RAMS consideration appropriately addressed
- human factors considerations as appropriate

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- systems architecture
- 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 contains a list of sections to be included in the SEMP as a minimum.

The objective or need for a change in transport functional or performance capability forms the basis for the business requirements 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 new or altered system. SE as an engineering methodology cannot be carried out in isolation of project management, safety assurance, risk management and procurement management.

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.

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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 the SE technical processes to be followed, including limits of control, responsibilities, deliverables, tools and controlling standards and procedures. The 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 as shown in Figure 15. It is important to note that the SEMP and other key SE related plans are living documents.

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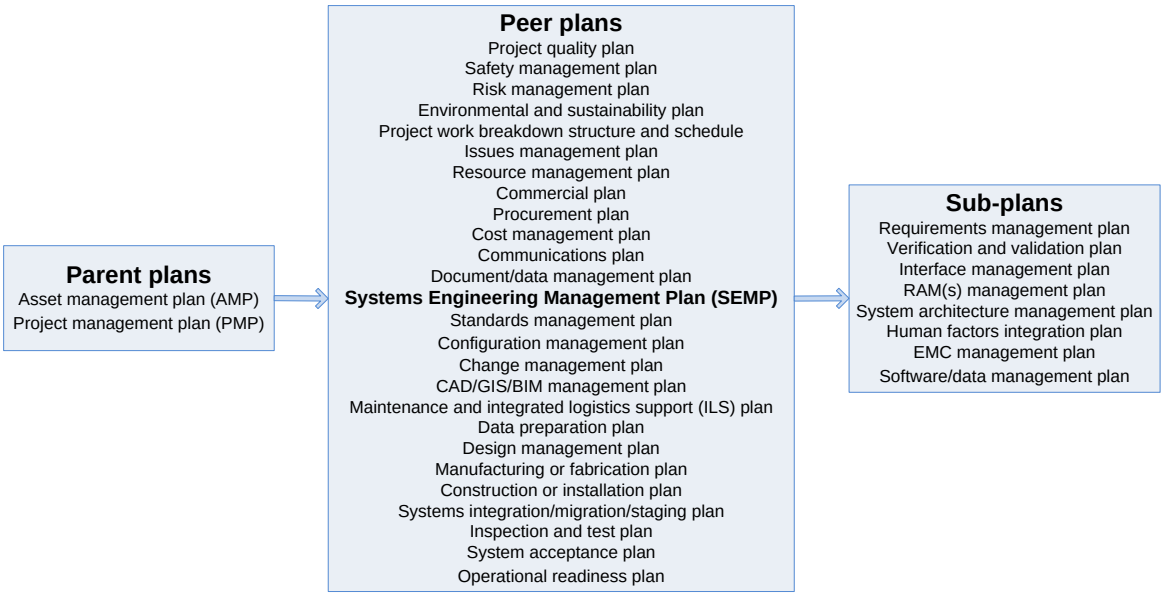

Figure 15 - Shared information

11.5.1. Parent plans

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 the 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 the 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

The SEMP is the governing plan that controls the entire systems engineering effort and all technical aspects of the project. There are elements in the SEMP which are detailed further by the project team in other plans. A large project with high complexity, novelty and risk will contain the peer plans, such as project quality plan, safety management plan, commercial plan, communication plan, operational readiness plan and so on as shown in Figure 15, depending on the type of system to be delivered.

Note: For smaller projects some of the plans listed could be combined, or may not be required. The person responsible for planning and managing SE should assess the level of detail required, in consultation with the project manager, based on the expected level of novelty, complexity, scale and risk of the project. To justify the reduction or exclusion of some SE activities, a coherent assurance argument is required.

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11.5.3. Sub-plans

The SEMP covers all of the major systems engineering functions and it may do so by referring to other subordinate plans such as those shown in Figure 15 as 'sub-plans'. These sub-plans focus on key technical and technical management processes for the project such as; human factors, requirements, system architecture, interface management and configuration management to name a few.

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 SE 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 and 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. Requirements definition process

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 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

Requirements management processes are used to define the requirements for a system to achieve the following:

- transform the requirements into an effective system
- use the system to provide the required services

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- sustain the provision of those services
- dispose of the system or system elements when it is retired from service

In order to achieve a new or altered service capability, the enterprise goals and needs are identified by the sponsor developing service level agreements with operating agencies, analysing customers' needs into requirements and transport planners. However, in some cases it is possible that the operator and maintainer 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.

12.1.1. Business requirements

The BRS is produced by the business unit responsible for strategic and transport planning, with stakeholder input from the entities responsible for developing service level agreements, analysing customers' needs, and operator and maintainer. In some cases the BRS may be produced by the project delivery organisation. In other cases the operator and maintainer may still encounter situations where it may lead to the development of the BRS (for example, Sydney Trains specifying the ROC business requirements or NSW Light rail specifying Operations Control Centre 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 OCD that describes the operational activities required to support the operational capability
- produce a MCD that describes the maintenance activities required to support the operational capability
- produce a business case and associated BRS
- produce a ConOps that provides an overarching high-level view of the organisation, its goals and objectives to direct the overall characteristics of the future business and systems required to operate the business
- conduct all performance modelling and analysis to support production of these deliverables

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

Further guidance on developing a BRS can be obtained from T MU AM 06010 GU.

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12.1.2. System requirements

The system requirements specification (SRS) is produced by the project delivery office often with support from an experienced AEO acting as the technical advisor and with stakeholder inputs obtained from the operator and maintainer and other TfNSW stakeholders as needed.

Depending on the commercial contract, the delivery organisation responsible for developing the SRS may not always be the project delivery office within TfNSW.

In some cases the SRS may be produced by the operator and maintainer.

The following activities are carried out in order to produce an SRS:

- develop the concept design up to a (costed) reference design
- develop the 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.*

12.2. Requirements analysis process

When a 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.

When a 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 vehicle, bus vehicle, road traffic signals, railway 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.

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).

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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.

For high-complexity projects that can contain a large number of requirements, a dedicated commercial of 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 spread sheet or similar tool (RATM/RVTM).

Various parts of TfNSW 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.

12.3. System architectural design process

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.

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Examples of functional, physical, geographical and interface architectures that are synthesised and developed under the system architectural design process are described in Section 7.6, Section 7.7, Section 7.8 and Section 7.9.

Further guidance is provided in T MU AM 06001 GU *Guide to System Architectural Design* and T MU AM 06003 TI *Development of a Transport Network Architecture Model*.

12.4. 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.

12.5. Interface and integration process

Interface management is the collection of activities to ensure that discrete elements and systems can function together. Systems integration involves bringing together component elements or subsystems into one system, ensuring that they function together as a complete system, and ensuring the new system integrates with the existing system of systems.

The requirements for system interface management and integration management is stated in T MU AM 06006 ST.

12.5.1. Technical interface management

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 managing the technical system interfaces, and is not limited to organisation or contract interfaces.

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.

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

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 either by a design manager or by a dedicated interface manager for high complexity systems.

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 a level that is reasonably practicable.

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 using 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.

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12.5.2. Systems integration management

Systems integration (including operational integration activities), while carried out on the right hand side of the V life cycle model after installation and before commissioning, is an activity that should be planned well in advance, on the left hand side of the V life cycle 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 the integration and testing activities, along with acceptance criteria.

During system integration, designers should be available to support testing and commissioning staff 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.

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 through 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.

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 TNAC as an interim commissioned system (that is TNAC Gate 5). In most cases, interim configurations are managed as a change through the local delivery organisation's CCBs.

Further guidance is provided in the T MU AM 06014 GU *Guide to Systems Integration*.

12.6. Verification and validation process

While ISO 15288 separates the verification and validation (V&V) technical processes, this document combines them as closely related activities.

V&V often use the same processes, tools and methods, but for achieving different assurance outcomes at different stages in the project life cycle of the system.

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

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

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

The organisation, roles and responsibilities for verification activities may be different to validation activities. For software specific projects such as communication based interlocking data sets or ATRICS system, a separate verification plan and report may be developed by a verifier to examine the completeness, correctness and consistency of the software in accordance to the system and subsystem level specifications. While it may be railway focused, further information and guidance on V&V specific activities and roles can be found in EN 50128:2001.

During the acquire stage, the V&V plan should undergo changes throughout the preliminary and detailed design phases to document the required V&V activities such as systems integration tests (SIT), site acceptance tests (SAT) and factory acceptance tests (FAT).

The verification process spans through the system life cycle from the concept and specify phase 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. For low complexity projects, this may be done through a RVTM spreadsheet.

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.

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.

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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. For low complexity projects, a RVTM spreadsheet may be developed in lieu of a complex requirements management system.

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 and TS 10506 *AEO Guide to Verification and Validation*.

12.7. Transition process

Within the TfNSW context, transition means the activities associated with transferring the system into operational use, from the delivery project to the operator and maintainer, which is achieved by the commissioning and operational readiness and integration activities. The operational readiness report reflects the satisfactory completion of the following activities:

- all commissioning tests completed and successful
- all safety risks controlled or transferred to and accepted by the operator and maintainer
- 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

12.8. Operation process

Project perspective and operator and maintainer perspective are the two aspects to operations process, that systems engineering should consider.

During the plan, specify, develop and acquire phases of a new or altered system, the project should consider the system operations over its full operational life time (operability and operational availability analysis). This information should be captured through the project OCD and updated as the system design matures.

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

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12.9. Maintenance process

Project perspective and operator and maintainer perspective are the two aspects to maintenance process that systems engineering should consider.

During the plan, specify, develop and acquire phases 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
- maintenance staffing levels and staffing requirements
- built-in-test (BIT) capability
- maintenance and fault diagnostic aids
- remote and predictive maintenance
- failure isolation

This information should be captured through the MCD that is developed early in the plan phase of the life cycle and updated as the system design matures.

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

12.10. 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.

12.11. 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,

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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.

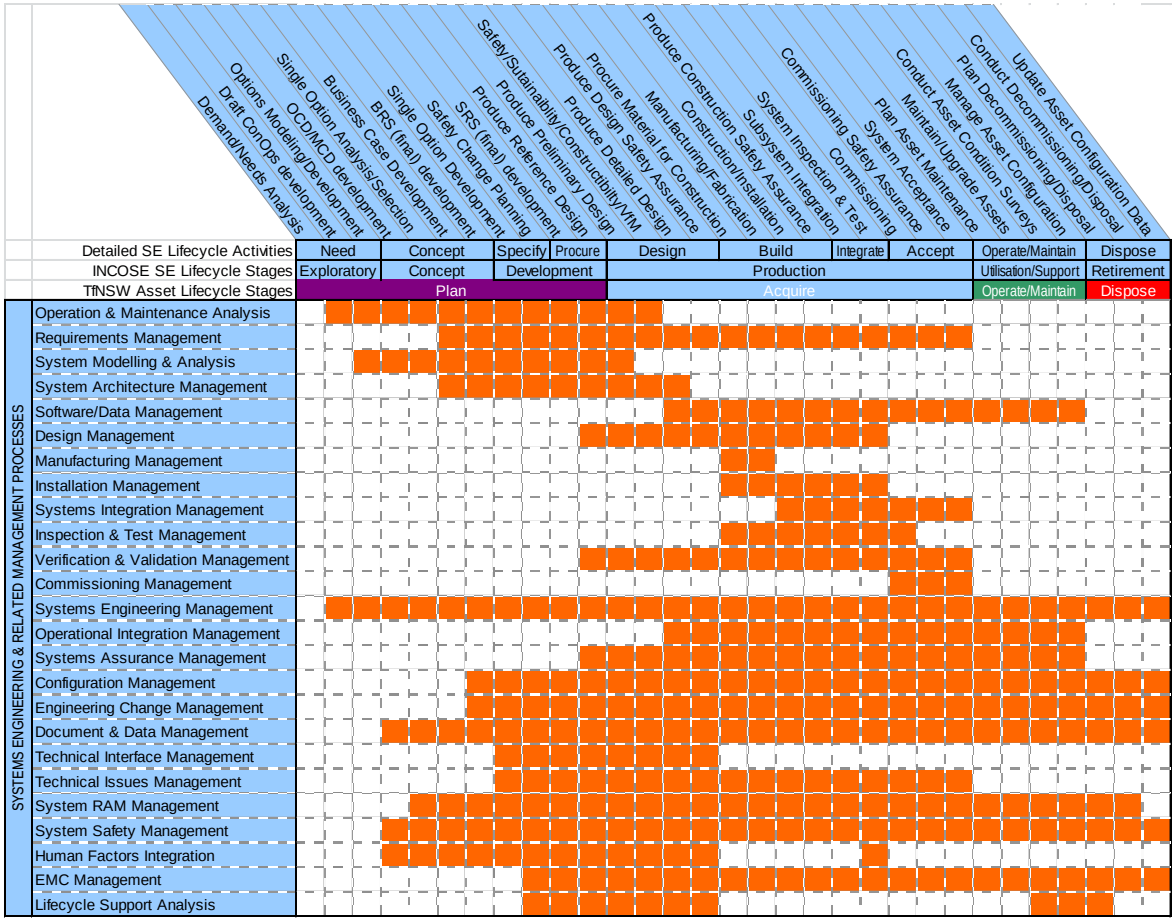

Figure 16 - SE process mapping to life cycle

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

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.

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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: 2013 *AEO Guide to Engineering Management* and AS/RISSB 7722 *EMC Management*. For the purposes of railway engineering, the EN 50121 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 T MU MD 20001 *System Safety Standard for New or Altered Assets*.

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.

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.

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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 operator and maintainer.

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 sources. 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 degraded modes of operation.

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. Human factors can assist with designing systems that take into account human capabilities and limitations, thus improving reliability.

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. However, major changes to parts of the system require a RAMS assessment to maintain or at least improve the integrity of the system.

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.

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 the following standards:

- T MU AM 06002 GU *AEO Guide to Reliability, Availability and Maintainability*
- TS 10504: 2013 *AEO Guide to Engineering Management*

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- EN 50126-1 *Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic Requirements and Generic Process*
- AS/NZS ISO/IEC 15288 *Systems and software engineering—System life cycle processes*

13.3. HFI management

The study of 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 human-system interaction in the development of the system solution, in order to ensure an effective and efficient system, and provide assurance that new risks (including safety) are not introduced at the human-machine interface.

For more detailed requirements and guidance on human factors integration, refer to the following documents.

- 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*

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
- organisational project-enabling 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.

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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 framework)
- infrastructure management process (TfNSW asset management framework)
- project portfolio management process
- human resource management process
- quality management process (quality management system of TfNSW and agencies)

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 (TfNSW project delivery process and operator and maintainer project planning processes)
- project assessment and control process (TfNSW project delivery process and operator and maintainer project control processes)
- project decision management process (TfNSW project delivery and operator and maintainer project processes)
- project risk management process
- project configuration management process
- project information management process
- project measurement process

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14.4. Tailoring processes

Tailoring and scaling of the application of SE as defined in T MU AM 06006 ST to a project should balance assurance of delivery of stakeholder and 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 were 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

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Appendix A Example of SEMP structure

A.1. SEMP structure

The SEMP should contain the following information, but not limited to:

- organisation of the project and how SE interfaces with other parts of the organisation
- responsibilities and authority of the key SE positions
- system boundaries and scope of the project
- assumptions, dependencies and constraints
- key technical objectives
- risk and opportunity plan, assessment, and methodology
- verification and validation planning
- configuration management planning
- QA planning
- infrastructure support and resource management (that is, facilities, tools, IT, personnel, and so on)
- reliability, availability, maintainability, durability (for civils/structures) supportability, and integrated logistics support (ILS)
- resilience (for global climatic change events, earthquakes, catastrophic fires and major subsidence)
- EMC, radio frequency management, and electrostatic discharge
- human factors integration
- safety, health and environmental impact
- system security
- manufacturability or constructability
- test and evaluation
- testability and integrated diagnostics
- computer resources and SE tools
- transportability
- other engineering specialties that determine performance and functional requirements

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Note: The SEMP structure obtained from INCOSE SE Handbook is modified to suit TfNSW.

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Appendix B Examples of SE application effort and scaling

Table 2 identifies a range of typical transport 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

Level	Project Example	Project Scale ($/time)	Complex	Novelty	Unmitigated project risk	SE effort	ReqM	Interface	V&V	Sys Arch	RAMS	EMC	HFI
Project	At-grade car park	Small	Low	Low	Low	Light	L	L	L	L	L	-	L
	Bus stop (single)	Small	Low	Low	Low	Light	L	L	L	L	L	L	L
	OHW (new/altered)	Small	Low	Low	Low	Light	L	L	L	L	L	L	-
	HV feeder 66/33/11 kV (new/altered)	Small	Low	Low	Low	Light	L	L	L	L	L	M	-
	Multi-story car park	Medium	Medium	Low	Medium	Medium	M	M	M	L	L	-	M
	Traction substation (single)	Medium	Medium	Low	Medium	Medium	M	M	H	M	M	M	M
	Station (small to medium, new/altered, single)	Medium	Medium	Medium	Medium	Medium	M	M	M	M	H	M	M
	Transport interchange or light rail stop (major, single)	Large	High	Medium	Medium	Medium	H	H	H	M	H	M	H
	Stabling yard (single)	Large	High	Low	Medium	Medium	H	H	H	M	H	M	H
Program	Major track or road renewals (corridor/network)	Large	Low	Low	Medium	Light	L	M	M	L	M	-	-
	New bus fleet procurement	Large	Medium	Medium	Medium	Medium	M	M	M	M	H	M	H
	Transport access program (network)	Large	Medium	Medium	Medium	Medium	M	H	H	M	M	L	H
	Automatic train protection (network)	Large	High	High	High	Heavy	H	H	H	H	H	H	H
	New rolling stock fleet procurement (network/line)	Large	High	High	High	Heavy	H	H	H	H	H	H	H
	Traction power supply upgrade (network)	Large	High	Medium	High	Heavy	H	H	H	H	H	H	M
	Signalling technology upgrade (network level – road and rail)	Variable	High	High	High	Heavy	H	H	H	H	H	H	H
	Corridor/line upgrade (brown field)	V Large	High	High	High	Heavy	H	H	H	H	H	H	H
	Corridor/line new build (green field)	V Large	High	High	High	Heavy	H	H	H	H	H	H	H
Portfolio	Sydney's rail future (network/multiple programs)	V Large	V High	V High	V High	Heavy	H	H	H	H	H	H	H
	Sydney's Light rail future (CBD & SELR, Newcastle, Parramatta)	V Large	V High	V High	V High	Heavy	H	H	H	H	H	H	H
	Sydney's Ferry future (wharves and fleet)	V Large	V High	V High	V High	Heavy	H	H	H	H	H	H	H

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Appendix C Specific and generic system life cycles

Figure 17 and Figure 18 depicts the multiple system life cycles and V life cycle model for multi-disciplinary, staged rail engineering project, respectively.

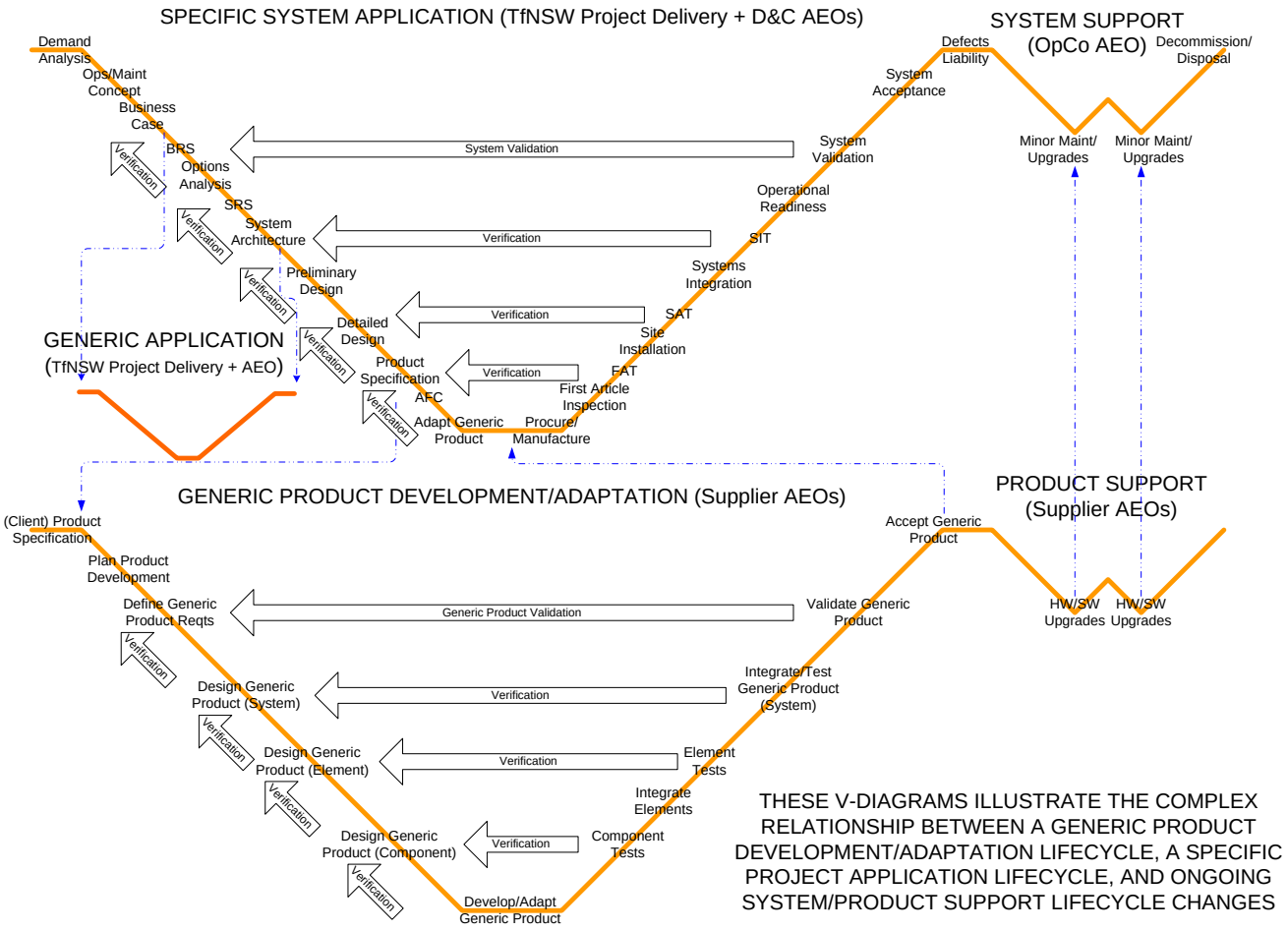

Figure 17 – Multiple system life cycles

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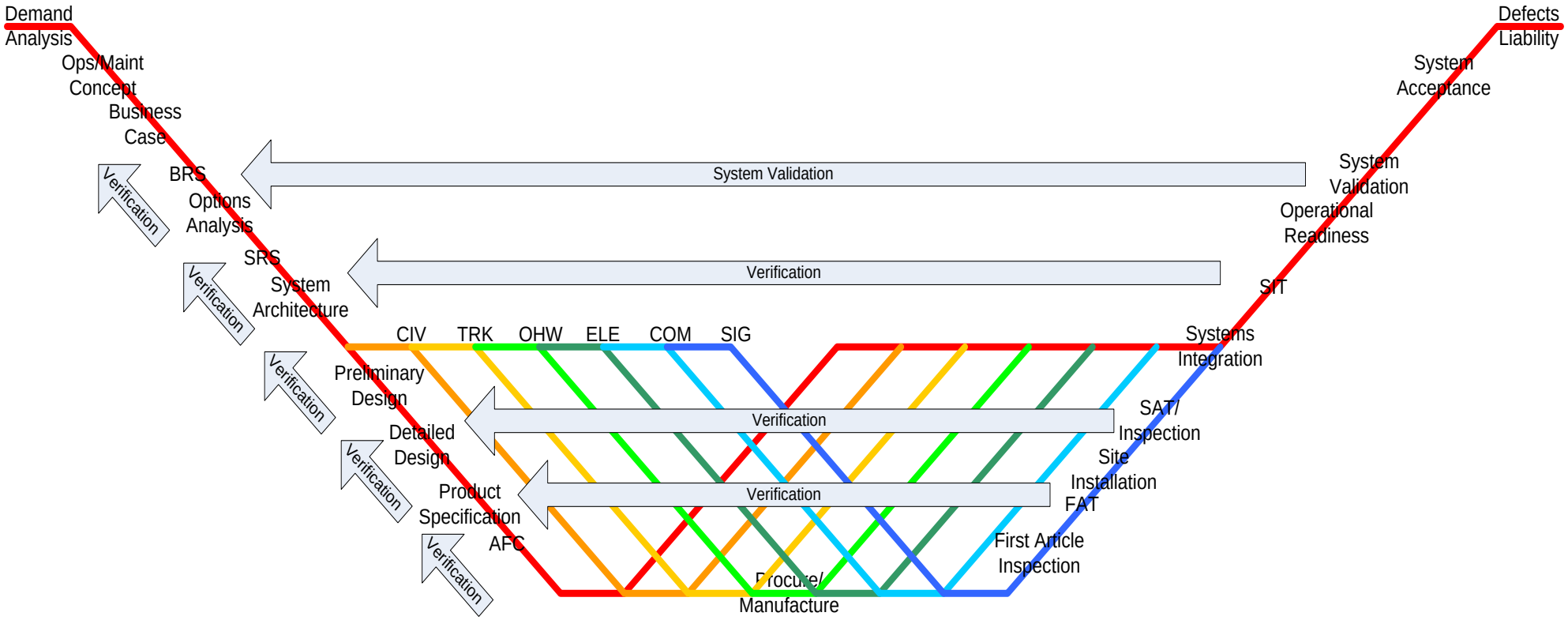

Figure 18 – V life cycle model for multi-disciplinary, staged rail engineering project

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Appendix D Example of a light rail system

Figure 19 illustrates the light rail system.

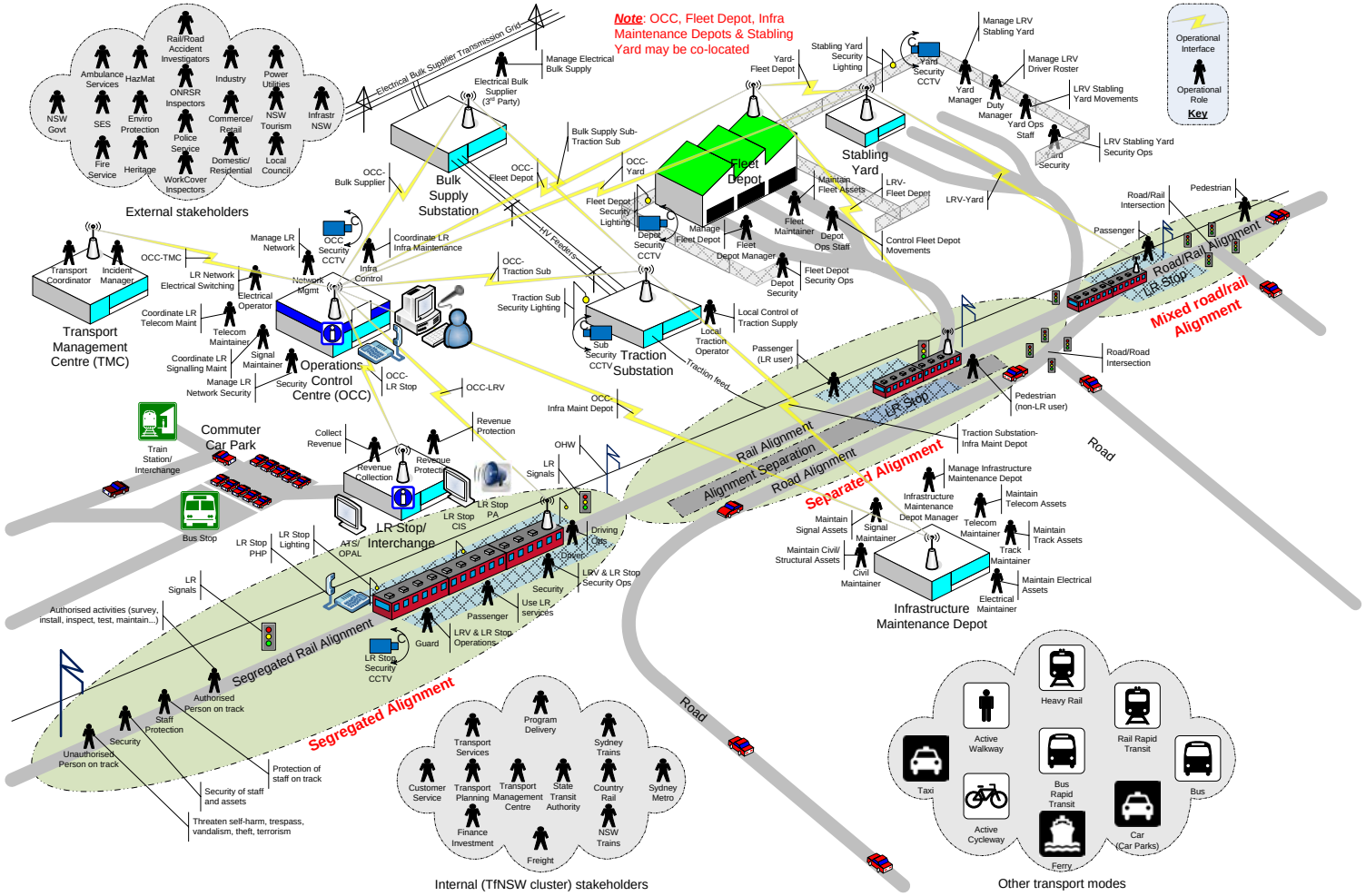

Figure 19 – Example of a light rail system

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Appendix E TfNSW asset classification scheme

Figure 20 shows the TfNSW asset classification scheme that is extracted from T MU AM 02002 TI *Asset Classification System*.

3. Asset classifications

T MU AM 02002 TI
Asset Classification System
Version 1.10
Issued date: 11 May 2017

Table 4 provides details on asset classifications.

Table 4 - Asset classifications

Di	Discipline	Cla	Class description	Functi	Function description	Ty	Type description	Categor	Capitalise	Financia	Technical	Object description
AR	Architecture & Services	BD	Buildings & Access	ARMP	Access Ramp			Non Linear	Yes	Buildings	BD-ARMP	Access Ramp
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	AM	Amenities	Non Linear	Yes	Buildings	BD-BLDG-AM	Amenities Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	BS	Bicycle Shed	Non Linear	Yes	Buildings	BD-BLDG-BS	Bicycle Shed Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	DP	Depot	Non Linear	Yes	Buildings	BD-BLDG-DP	Depot Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	FD	Fuel Shed	Non Linear	Yes	Buildings	BD-BLDG-FD	Fuel Shed
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	LA	Laboratory	Non Linear	Yes	Buildings	BD-BLDG-LA	Laboratory Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	OF	Office/Admin	Non Linear	Yes	Buildings	BD-BLDG-OF	Office/Admin Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	OP	Operations	Non Linear	Yes	Buildings	BD-BLDG-OP	Operations Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	RE	Retail	Non Linear	Yes	Buildings	BD-BLDG-RE	Retail Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	RS	Residential	Non Linear	Yes	Buildings	BD-BLDG-RS	Residential Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SB	Signal Box	Non Linear	Yes	Buildings	BD-BLDG-SB	Signal Box Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SD	Storage Shed	Non Linear	Yes	Buildings	BD-BLDG-SD	Storage Shed Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SH	Section Hut	Non Linear	Yes	Buildings	BD-BLDG-SH	Section Hut Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SN	Station	Non Linear	Yes	Buildings	BD-BLDG-SN	Station Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SS	Substation	Non Linear	Yes	Buildings	BD-BLDG-SS	Substation Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	SV	Services	Non Linear	Yes	Buildings	BD-BLDG-SV	Services Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	TR	Training	Non Linear	Yes	Buildings	BD-BLDG-TR	Training Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	TS	Tunnel Services	Non Linear	Yes	Infrastructure	BD-BLDG-TS	Tunnel Services Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	WA	Wash/Presentation	Non Linear	Yes	Buildings	BD-BLDG-WA	Wash/Presentatn Bldg
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	WH	Warehouse	Non Linear	Yes	Buildings	BD-BLDG-WH	Warehouse Building
AR	Architecture & Services	BD	Buildings & Access	BLDG	Building-Permanent	WO	Workshop	Non Linear	Yes	Buildings	BD-BLDG-WO	Workshop Building
AR	Architecture & Services	BD	Buildings & Access	BLDP	Building-Portable			Non Linear	Yes	Buildings	BD-BLDP	Portable Building
AR	Architecture & Services	BD	Buildings & Access	BRMP	Boat Ramp			Non Linear	Yes	Infrastructure	BD-BRMP	Boat Ramp
AR	Architecture & Services	BD	Buildings & Access	CNPY	Canopy	BU	Bus Stop	Non Linear	Yes	Buildings	BD-CNPY-BU	Canopy-Bus Stop
AR	Architecture & Services	BD	Buildings & Access	CNPY	Canopy	DP	Depot	Non Linear	Yes	Buildings	BD-CNPY-DP	Canopy-Depot
AR	Architecture & Services	BD	Buildings & Access	CNPY	Canopy	LR	LRV Stop	Non Linear	Yes	Buildings	BD-CNPY-LR	Canopy-LRV Stop
AR	Architecture & Services	BD	Buildings & Access	CNPY	Canopy	TR	Train Station	Non Linear	Yes	Buildings	BD-CNPY-TR	Canopy-Train Station
AR	Architecture & Services	BD	Buildings & Access	CNPY	Canopy	WH	Wharf	Non Linear	Yes	Buildings	BD-CNPY-WH	Canopy-Wharf
AR	Architecture & Services	BD	Buildings & Access	CONC	Concourse			Non Linear	Yes	Buildings	BD-CONC	Concourse
AR	Architecture & Services	BD	Buildings & Access	GWAY	Gangway			Non Linear	Yes	Buildings	BD-GWAY	Gangway (Access)
AR	Architecture & Services	BD	Buildings & Access	JETY	Jetty			Non Linear	Yes	Buildings	BD-JETY	Jetty
AR	Architecture & Services	BD	Buildings & Access	PIER	Pier			Non Linear	Yes	Buildings	BD-PIER	Pier
AR	Architecture & Services	BD	Buildings & Access	PLAT	Platform	LR	LRV Stop	Linear	Yes	Buildings	BD-PLAT-LR	Platform-LRV Stop
AR	Architecture & Services	BD	Buildings & Access	PLAT	Platform	TR	Train Station	Linear	Yes	Buildings	BD-PLAT-TR	Platform-Train Stn
AR	Architecture & Services	BD	Buildings & Access	PLTH	Plinth			Non Linear	Yes	Buildings	BD-PLTH	Plinth
AR	Architecture & Services	BD	Buildings & Access	PONT	Pontoon			Non Linear	Yes	Buildings	BD-PONT	Pontoon
AR	Architecture & Services	BD	Buildings & Access	STRS	Stairs	AC	Access	Non Linear	Yes	Buildings	BD-STRS-AC	Stairs-Bldg Access
AR	Architecture & Services	BD	Buildings & Access	STRS	Stairs	FI	Fire	Non Linear	Yes	Buildings	BD-STRS-FI	Stairs-Fire
AR	Architecture & Services	BD	Buildings & Access	STRS	Stairs	TP	Track to Platform	Non Linear	Yes	Buildings	BD-STRS-TP	Stairs-Trk to Platfm
AR	Architecture & Services	BD	Buildings & Access	STRS	Stairs	TT	Train to Track	Non Linear	Yes	Buildings	BD-STRS-TT	Stairs-Train to Trk
AR	Architecture & Services	BD	Buildings & Access	WALK	Walkway			Non Linear	Yes	Buildings	BD-WALK	Walkway-Bldg Access
AR	Architecture & Services	CA	Compressed Air Systems	AIRD	Air Dryer			Non Linear	No, with parent system		CA-AIRD	Air Sup-Air Dryer
AR	Architecture & Services	CA	Compressed Air Systems	AIRM	Air Main			Linear	No, with parent system		CA-AIRM	Air Sup-Main
AR	Architecture & Services	CA	Compressed Air Systems	AIRR	Air Receiver			Non Linear	No, with parent system		CA-AIRR	Air Sup-Air Receiver
AR	Architecture & Services	CA	Compressed Air Systems	AIRS	Air Supply System	DP	Depot	Non Linear	Yes, each system	Buildings	CA-AIRS-DP	Air Supply Sys-Depot

Figure 20 – TfNSW asset classification scheme)

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Appendix F Example of interface control document matrix

Figure 21 shows an example of the interface control document matrix.

ICD MATRIX	Signalling Systems	Telecoms & Data Network	Control Systems	Electrical Substation	Overhead Wiring	Track Systems	General Civils	Bridges & Structures	Stations & Interchanges	Yards & Depots	Rolling Stock
Signalling Systems	*ICD Code:* 1.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-10 *Owner:* Joe Bloggs	1.02 ABC Entity XXX-ICD-11 Joe Bloggs	1.03 ABC Entity XXX-ICD-12 Joe Bloggs	1.04 ABC Entity XXX-ICD-13 Joe Bloggs	1.05 ABC Entity XXX-ICD-14 Joe Bloggs	1.06 ABC Entity XXX-ICD-15 Joe Bloggs	1.07 ABC Entity XXX-ICD-16 Joe Bloggs	1.08 ABC Entity XXX-ICD-17 Joe Bloggs	1.09 ABC Entity XXX-ICD-18 Joe Bloggs	1.10 ABC Entity XXX-ICD-19 Joe Bloggs
	Telecoms & Data Network	*ICD Code:* 2.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-20 *Owner:* Joe Bloggs	2.02 ABC Entity XXX-ICD-21 Joe Bloggs	2.03 ABC Entity XXX-ICD-22 Joe Bloggs	2.04 ABC Entity XXX-ICD-23 Joe Bloggs	2.05 ABC Entity XXX-ICD-24 Joe Bloggs	2.06 ABC Entity XXX-ICD-25 Joe Bloggs	2.07 ABC Entity XXX-ICD-26 Joe Bloggs	2.08 ABC Entity XXX-ICD-27 Joe Bloggs	2.09 ABC Entity XXX-ICD-28 Joe Bloggs
		Control Systems	*ICD Code:* 3.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-30 *Owner:* Joe Bloggs	3.02 ABC Entity XXX-ICD-31 Joe Bloggs	3.03 ABC Entity XXX-ICD-32 Joe Bloggs	3.04 ABC Entity XXX-ICD-33 Joe Bloggs	3.05 ABC Entity XXX-ICD-34 Joe Bloggs	3.06 ABC Entity XXX-ICD-35 Joe Bloggs	3.07 ABC Entity XXX-ICD-36 Joe Bloggs	3.08 ABC Entity XXX-ICD-37 Joe Bloggs
			Electrical Substation	*ICD Code:* 4.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-40 *Owner:* Joe Bloggs	4.02 ABC Entity XXX-ICD-41 Joe Bloggs	4.03 ABC Entity XXX-ICD-42 Joe Bloggs	4.04 ABC Entity XXX-ICD-43 Joe Bloggs	4.05 ABC Entity XXX-ICD-44 Joe Bloggs	4.06 ABC Entity XXX-ICD-45 Joe Bloggs	4.07 ABC Entity XXX-ICD-46 Joe Bloggs
				Overhead Wiring	*ICD Code:* 5.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-50 *Owner:* Joe Bloggs	5.02 ABC Entity XXX-ICD-51 Joe Bloggs	5.03 ABC Entity XXX-ICD-52 Joe Bloggs	5.04 ABC Entity XXX-ICD-53 Joe Bloggs	5.05 ABC Entity XXX-ICD-54 Joe Bloggs	5.06 ABC Entity XXX-ICD-55 Joe Bloggs
					Track Systems	*ICD Code:* 6.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-60 *Owner:* Joe Bloggs	6.02 ABC Entity XXX-ICD-61 Joe Bloggs	6.03 ABC Entity XXX-ICD-62 Joe Bloggs	6.04 ABC Entity XXX-ICD-63 Joe Bloggs	6.05 ABC Entity XXX-ICD-64 Joe Bloggs
						General Civils	*ICD Code:* 7.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-70 *Owner:* Joe Bloggs	7.02 ABC Entity XXX-ICD-71 Joe Bloggs	7.03 ABC Entity XXX-ICD-72 Joe Bloggs	7.04 ABC Entity XXX-ICD-73 Joe Bloggs
							Bridges & Structures	*ICD Code:* 8.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-80 *Owner:* Joe Bloggs	8.02 ABC Entity XXX-ICD-81 Joe Bloggs	8.03 ABC Entity XXX-ICD-82 Joe Bloggs
								Stations & Interchanges	*ICD Code:* 9.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-90 *Owner:* Joe Bloggs	9.02 ABC Entity XXX-ICD-91 Joe Bloggs
									Yards & Depots	*ICD Code:* 10.01 *Administration:* ABC Entity *Document No.:* XXX-ICD-100 *Owner:* Joe Bloggs
										Rolling Stock	*ICD Code:* *Administration:* *Document No.:* *Owner:*

Figure 21 – Example of interface control document matrix

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