Sustainable Built Environment National Research Centre AUSTRALIA

Project 2.51
Developing a Cross-Sector Digital Asset Information Model Framework for Asset Management

Final Research Report

November 2019

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Project Participants

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Project Partners

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Project Web Page: https://sbenrc.com.au/research-programs/2-51/

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Preface

The Sustainable Built Environment National Research Centre (SBEnrc), the successor to Australia's Cooperative Research Centre (CRC) for Construction Innovation, is committed to making a leading contribution to innovation across the Australian built environment industry. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness.

We encourage you to draw on the results of this applied research to deliver tangible outcomes for your operations. By working together, we can transform our industry and communities through enhanced and sustainable business processes, environmental performance and productivity.

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Executive Summary

Asset management is the systematic process of deploying, operating, maintaining, upgrading and disposing of built environment assets. Effective asset management requires the involvement of all levels of an organisation in planning, control and monitoring of asset performance that combines management, financial, economic and other activities and practices.

Over the past decade, Building Information Modelling (BIM), as an intelligent 3D model-based process to inform and communicate project decisions, has received much attention in the design and construction stages of buildings and transport infrastructure. However, the use of BIM for asset management has only recently been recognised in terms of its benefits to managing assets when using 3D models.

This SBEnrc Project 2.51 initially focussed on a comprehensive review of current digital asset management practices in order to promote BIM and other digital engineering technologies for more effective use in informed asset management decisions. This was done for the four core areas of asset data exchange, asset classification, asset location referencing and asset information requirements.

This report is one of a suite of three reports generated within Project 2.51 “Developing a Cross-Sector Digital Asset Information Model Framework for Asset Management”. It presents information likely to be of more interest to academics and researchers so that they can more fully understand how the material in the other reports was developed. The other complimentary reports are:

- The *Digital Asset Information Management: A Guide and Manual* provides material that will be used directly by industry practitioners in increasing the level of use of BIM-based technologies in the implementation or improvement of asset management systems within their organisations.
- The *Digital Asset Information Management: Case Studies* report presents a range of scenarios across residential and building facilities and transport infrastructure. This is intended to provide an overview of existing asset management practices to inform industry of the possibilities and to provide background for strategic planning of asset management uptake.

Following the review of current practice, this *Digital Asset Information Management: Research Report* was developed to provide in depth information about aspects of the project. The information provided herein covers:

1. Asset management as a process;
2. Data exchange standards for asset management that support interoperability between asset management software tools and also to and from asset management databases;
3. The use of classification within asset management to provide structure to asset management information;
4. The need for location information for assets, both in absolute terms and with respect to other assets and components;
5. The requirements in representing asset information.

These topics all provide material that will enable a deeper understanding of the material presented in the other two Project 2.51 reports.

1 Introduction

Asset management in the built environment has been the subject of changing practice and research for many years and is often complicated by inconsistency in naming, measuring and monitoring the condition and performance of assets across the industry. This project, with an overarching approach across housing, buildings and transport infrastructure, has developed a Digital Asset Information Delivery Manual to support the operation and maintenance of key assets. Enabling information management technologies were examined and a framework for capturing, structuring and exchanging asset information digitally was developed. This was guided by the practical application of asset management on existing structures. This will aid the wider adoption and consistent curation of digital information for maintaining and operating assets across the construction supply chain, improving the efficiency of managing community assets, improving the return on investment and ensuring sustainability, resilience and safety.

The above implies that this project focusses on the information that needs to be collected and maintained to support the entire asset management process. Section 1.2 provides the context for the work covered by this project within the overall asset management process.

This project will assist in the expansion of the use of digital information modelling, such as BIM (Building Information Modelling) and DE (Digital Engineering), beyond design and construction to encompass asset management practices. The developed asset information model framework and delivery manual is supported by cross-sector case studies. This will enable access to asset information and the identification of opportunities for adding value to assets by enhancing the quality and use of digital asset data. These outcomes will serve as a foundation for continued development of a digital asset information models to aid management over asset lifecycles, identifying ways of decreasing the cost of operation and maintenance, and of improving the return on investment of asset management whilst concurrently improving sustainability, resilience and safety.

Within this document, the term BIM (Building Information Modelling) will be used where appropriate to describe computer-based representations of an asset. BIM software will normally generate 3D geometry associated with an asset together with lists of relevant property values. However, 3D geometry is not essential for the use of BIM in asset management. For example, a light fitting (luminaire) may just be referenced by its manufacturer, model number, location, switching and circuit.

Digital Engineering (DE) is used to cover software tools that create, define and modify BIM data in a unified manner, normally through a shared database or through the exchange of files in a non-discipline specific format.

1.1 Document Structure

This document defines a digital asset information management framework which is composed of the following sections:

- **Asset Management Process**: describes a general asset management process according to numerous standards on asset management.
- **Asset Data Exchange Standards**: Reviews the most widely used open data exchange standards in both building and transportation infrastructure industries.
- **Asset Classification System**: Reviews existing asset classification systems, and proposes an overall asset classification system that integrates assets in both building and transportation infrastructure domains.
- **Asset Location Referencing**: Reviews existing asset location referencing methods for vertical and horizontal assets, and proposes a future direction of how to integrate these various methods.
- **Asset Information Requirement**: Classifies asset information into two categories: (1) data (graphical data and non-graphical data), (2) documents (manuals, plans, photos, drawing, models, certificates, licences and schematics), and summarises the level of detail of information required during asset life cycles.

1.2 Asset Management Overview

Asset management is the entire process of planning, programming, and system monitoring as they relate to maintaining an asset (Figure 1). Asset management concepts of data-supported decision-making, management systems, strong relationships between condition and performance, and an emphasis on trade-off and investment analysis are integral components of daily business that support the mission to meet the service requirements of assets. The concepts need to be part of the culture and should be strongly supported by upper management.

The overarching concept is the delivery of a service. An asset management system provides the information necessary to monitor the performance of a system against its service requirements and to track changes to the system that are necessary to maintain the required level of service. This is a wide definition, covering a range of activities, such as strategic planning, finance, project management, etc.

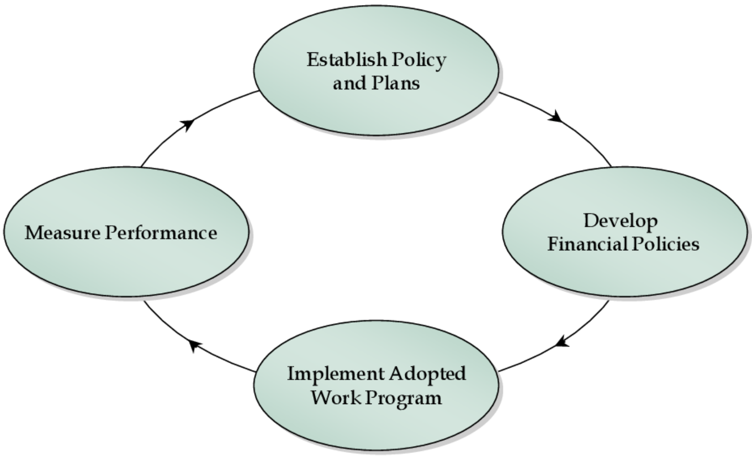

Figure 1: The concept of the Asset Management Process (Source: Florida's DOT's Concept of Asset Management)

Asset management is, at its core, a process of resource allocation and utilization. Resources in this context are interpreted broadly, encompassing financial, human, information, material, and equipment inputs to the management of the asset. The process of assigning or distributing these resources and applying them to the Agency's mission is likewise interpreted broadly, encompassing not only the traditionally understood functions in planning, program development, and budget approval, but also program delivery, system monitoring, data analysis, and input to policy formulation.

Asset management systems need to be closely aligned with organisational objectives if the maximum benefit is to be achieved. The types of assets and the management processes depend on:

- The nature and purpose of the organisation;
- The context within which it operates;
- Financial constraints and regulatory requirements; and
- Needs and expectations of the organisation and the stakeholders (AS ISO 55000:2014).

Asset management systems within the built environment will normally need to be cognisant of the regulatory requirements on individual assets, such as fire control systems, as well as those imposed on the organisation as a whole.

An appropriate asset management system assists in achieving value from the assets, while being balancing costs, risk and performance. An asset management system encapsulates the objectives of the organisation around "asset related decisions, plans and activities, using a risk-based approach" (AS ISO 55000:2014). EN 15221-1, which is being used as a source document for the Standards Australia facilities management standard uses a similar definition – "facilities management, integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities." Consequently, the term asset management will be used throughout this document.

The benefits of asset management can include:

1. Improved financial performance;
2. Informed investment decisions;
3. Managed risk;
4. Improved services and results;
5. Demonstrable social responsibility;
6. Demonstrable compliance;
7. Improved efficiency and effectiveness (AS ISO 55000:2014).

Asset management is characterised by:

- The adoption of an integrative approach (Institute of Asset Management, 2006; British Standard Institution (BSI), 2008; Edwards, 2010);
- Defining service levels and performance standards and limiting them to strategic planning objectives;
- An optimised investment decision-making approach;
- Adopting a long-term (lifecycle) approach to asset management (Worley, 2000);
- Demand and risk management (Department of Provincial and Local Government, 2010).

Effective asset management requires the involvement of all levels of an organisation in planning, control and monitoring of asset performance that combines management, financial, economic and other activities and practices applied to the management of property assets' (Institute of Asset Management, 2006b) in a systematic and coordinated manner (British Standard Institution, 2008).

The relationships between asset management, an asset management system and the asset management portfolio are shown in Figure 2.

Figure 2: The Organisational Context of Asset Management

The focus of this report is on the asset management information and activities required to provide and maintain the physical assets in housing, buildings and infrastructure. This information needs to interface with the other information systems required to deliver the required services, but the details of these other information systems beyond the required interfaces is out of scope.

The information required of an asset management system will vary between the different users, based on the needs of the users, the type and expense of the asset and the operation(s) being performed on an asset.

The development of an asset model framework requires:

1. The identification of the objects of interest within the assets;
2. The identification of the range of operations performed on these objects and constraints that may be placed on these operations;
3. Current state of support for digital capture of assets and their status;
4. Likely future support for digital capture of assets and their status, and how to transition from current to likely future states.

1.3 Digital Engineering and Asset Management

1.3.1 Definition of BIM and Asset Management

In recent years, while Building Information Modelling (BIM) has become an important strategy in building, construction and infrastructure sectors to improve productivity and health and safety, the use of BIM for asset management has only been recognised recently in terms of its benefits of managing assets when using 3D models.

BIM is an intelligent 3D model-based process to inform and communicate project decisions and communicate project decisions. The U.S. National BIM Standard (2012) defined BIM as a term with three linked functions, including Building Information Modelling, Building Information Model and Building Information Management. Building Information Modelling refers to the business process of generating and using building data in the lifecycle of buildings. Building Information Model refers to the digital representation of the physical and functional characteristics of a facility and Building Information Management is the process of utilizing digital building information for effective sharing.

According to BuildingSMART, asset management is the systematic process of deploying, operating, maintaining, upgrading and disposing of assets efficiently and effectively. BIM and asset information can work together to make informed decisions in areas such as bringing existing assets into BIM, developing new assets in BIM, operating and managing existing or new assets. Figure 3 demonstrates the potential uses of BIM in infrastructure projects.

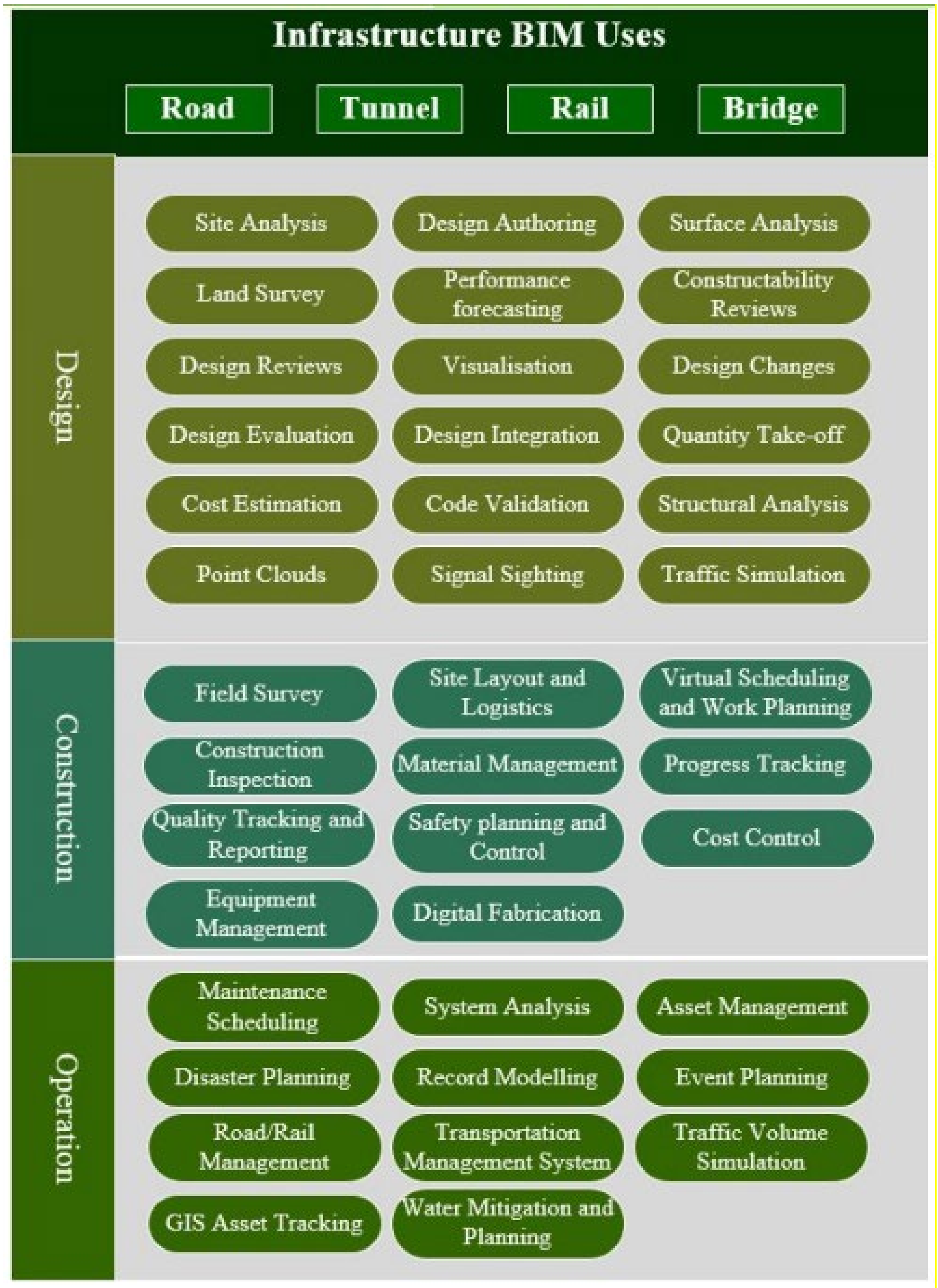

Figure 3: BIM uses in Infrastructure Projects

According to the Institute of Asset Management, the contribution of BIM to asset management can include:

- Asset register or inventory;
- Topographic data on the assets, and quantities derived;
- Asset condition data;
- Asset capability information
- Asset performance service levels, failure rates, etc.;
- Life expectancy data of equipment and materials;
- Descriptions of potential interventions for maintenance or renewal, and their costs;
- Contextual data, such as climate and surroundings;
- Asset history such as maintenance, alternations, renewals and replacements; and events such as accidents or other incidents.

1.3.2 Digital Asset Management

The Institute of Asset Management has also published a conceptual asset management model (Figure 4), which illustrates important pieces in asset management. These important pieces are also explained in details in the following sections.

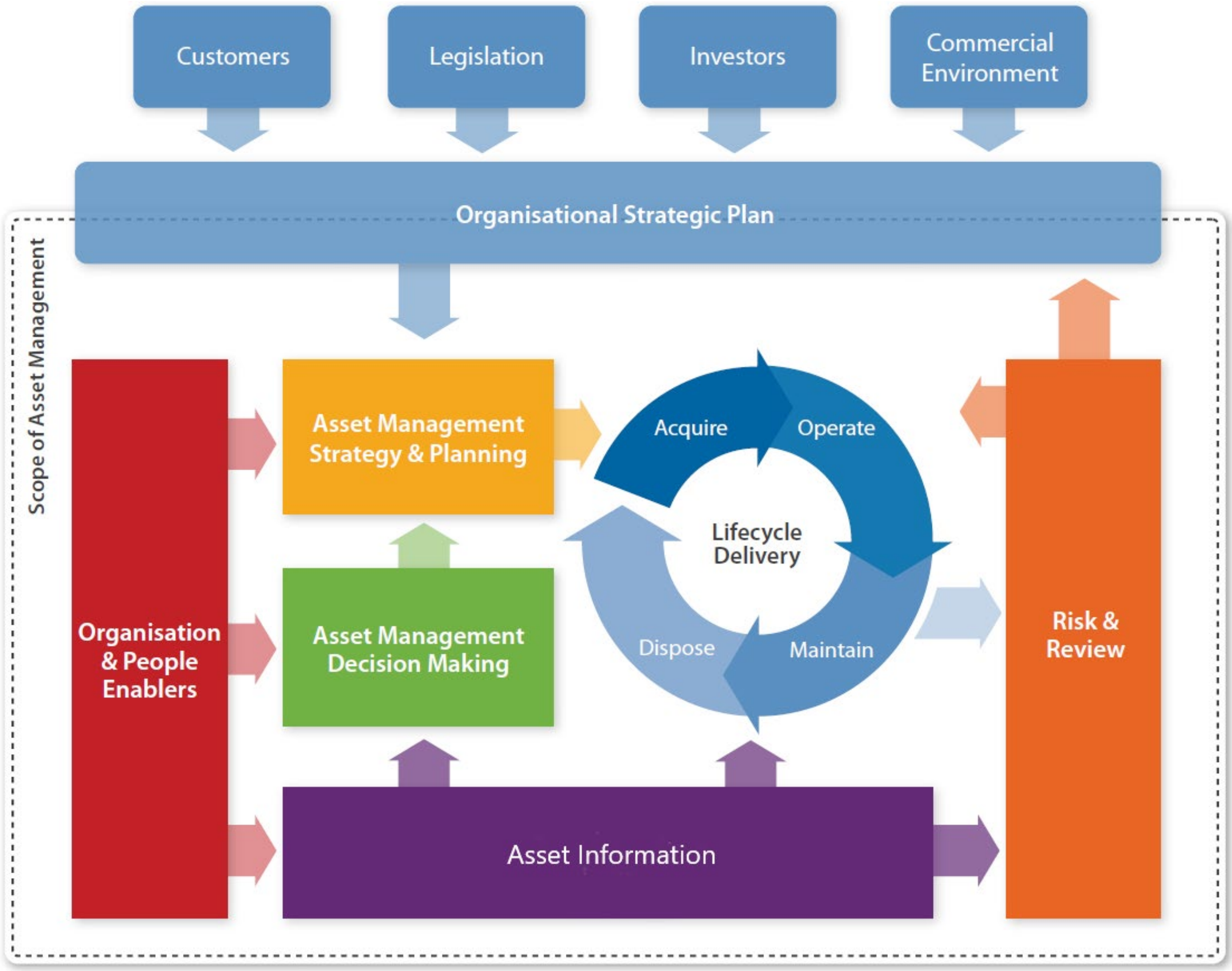

Figure 4: Asset Management Framework (Source: The Institute of Asset Management, 2015)

1.3.3 Asset Data Exchange Standard

Asset management involves the collaboration among various groups, including organisation and people, strategy and planning, risk, etc. These groups of people may use different format of data. As such, asset data exchange standard has always been a priority in asset management.

Interoperability is defined as a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions. It has been a core function of BIM.

IFC has been well developed in the building sector and recently BuildingSMART has initiated the development of IFC standard for infrastructure sectors. It is important that asset data exchange standard is addressed in developing a universal model for digital asset information management framework.

1.3.4 Asset Classification System

The naming system of each level of asset varies across states and authorities. However, some general rules are very common in both the building and infrastructure sectors. For example, the highest level of asset refers to the ones that can deliver high economic or community benefits. It is necessary that an asset information hierarchy, i.e. the classification system is developed.

1.3.5 Asset Location Referencing

One important issue to address when developing a universal digital asset information manual is the definition of location. The BIM community in the housing and building sector has treated location as where particular objects can be found in the building system, including storey, floor, room, grid coordinators, etc.

However, it should be noted that such criteria do not fit the characteristics of infrastructure sector, which relies on the geospatial coordinate terms. The definition of asset location referencing in the infrastructure sector should also focus on the network nature of infrastructure. Although a few attempts have been made on connected location (i.e. topological) location, geospatial location and linear location, more effort is needed.

1.3.6 Asset Information Requirement

Asset information requirement is the key area of digital asset management. Such information is needed to ensure that the overall set of data can be used for effective asset management over the asset life cycle.

Previously, much early work in BIM focuses on geometry and geometric construction information which is useful for the design and construction. Through time, as the assets move to the maintenance and operation stage, more asset attributes, e.g. condition data, are needed to make informed decision. It is therefore necessary to ensure that the detailed asset information requirement for each asset life cycle stage is clearly mapped.

1.4 International Standards and Best Practices

An international suite of standards provides guidance in asset management best practise. ISO 55001 focuses on the development of a proactive lifecycle asset management system. This supports optimisation of assets and reduces the overall cost of ownership while helping you to meet the necessary performance and safety requirements.

An asset management system provides a structured, best practice approach to managing the lifecycle of assets:

- Reduced risks associated with ownership of assets – anything from unnecessary maintenance costs and inefficiency to accident prevention (explosions at gas plants for example).
- Improved quality assurance for customers/regulators – where assets play a key role in the provision and quality of products and services.
- New business acquisition - stakeholders gain confidence from the knowledge that a strategy is in place to ensure assets meet the necessary safety and performance requirements.
- Supports international business growth – demonstrating that the requirements of an internationally recognised asset management system are being met.

In 2010, an ISO committee was created to develop a global standard for asset management and asset management systems:

- ISO55000:2014 Overview, Principles and Terminology.
- ISO55001:2014 Management Systems Requirements.
- ISO55002:2014 Management Systems Guidelines for the Application of ISO 55001.

Through an implemented asset management system, asset management offers a significant added value, alongside the operating product lifecycle of the physical assets (ISO 2014b). In asset-intensive industries, there are high expenditures in the operational maintenance of plant availability. For this reason, the asset management system is aligned with the facility management and maintenance areas of companies, whose business function is to secure technical availability and to minimise (constructive) weaknesses – according to the given economic conditions (ISO 2014b). In addition, an optimise "adjustment" between investments and operational expenses of assets aims at the achievement of maximum profitability (ISO 2014b).

1.4.1 Digital Asset Management

In an ideal world the development of a digital asset information system would start with a clean slate where the stakeholder requirements could be clearly identified, information on the assets easily captured and then fed into a purpose defined database with clear and specific user interfaces. Unfortunately, this is seldom, if ever, the case. A new digital asset management system will need to be able to incorporate data from existing systems, partial data that is gathered from existing assets for which no digital data exists, links to other relevant sources of information, such as financial databases, etc. There is no single system that can support all of the functions required to manage assets and, given that asset management is only one part of the business processes, it is unlikely that a single system will ever exist.

A number of studies have shown that:

1. Facility management requires extensive information and BIM has a great potential in this field (Becerik-Gerber et al. 2011);
2. Accurate as-built BIM models and robust definition of object requirements are needed for a proper implementation (Becerik-Gerber et al. 2011);
3. Non-geometrical data must be organised in a hierarchical structure, together with the connection with a responsibility matrix.” (Volk et al. 2014)
4. “Implementing BIM-based asset management procedures needs more effort when dealing with existing building than with new projects, mainly because of the need of surveying the existing building to gather correct data about quantities, dimensions, materials, and technologies (due to the common lack of updated as-built documents).” (Volk et al. 2014)
5. Most of the FM functions are handled manually, which indicates the great potential for a BIM-enabled FM that increases the FM efficiency and reduces human errors (Wang et al. 2013)

1.4.2 Building and Housing

This part of Project 2.51 is analysing the management of both residential and non-residential buildings as assets. The assumption is that the residential assets are leased by the asset owner to the occupiers. There are a range of owner/occupier relationships for non-residential assets:

1. Occupied by the asset owner, for example the same government department responsible for maintaining the asset occupies the premises;
2. Leased by the occupiers from a separate owner. A range of possible asset management relationships are possible here, ranging from total responsibility by the asset owner through to the owner only being responsible for the shell of the asset.

From an asset management perspective, the major differences between residential and non-residential assets lie in:

1. The division of responsibility in asset management. In residential assets most moveable contents will belong to the occupiers. The occupiers will normally be responsible for maintaining “consumable” assets (i.e. light globes, kitchen and bathroom consumables). In non-residential assets there are a range of possible ownership/management scenarios.
2. Statutory maintenance requirements. These will be minor for residential (i.e. fire alarms), but more onerous for multi-storey non-residential assets (i.e. fire extinguishers, lifts, mechanical plant).

1.4.3 Transportation and Infrastructure

The principles of asset management and pavement management are widely recognised in Australia and New Zealand, and the use of integrated information and predictive and optimising systems is increasing. The region's major road agencies began reporting the financial value of their assets in the late 1980s, and since 1997 all major road agencies have recognized road assets in annual financial statements (FHWA 2017). For more than a decade, the two countries have collaborated to advance their asset management programs.

A 1997 Austroads report, “Strategy for Improving Asset Management Practice”, lists 38 priority research and development actions for cooperative effort in Australia and New Zealand (Austroads 1997). Current activity includes developing standard guidelines for road condition measurement, refinement of models to predict road deterioration, accelerated testing, long-term monitoring to support the prediction of works effects, and correlation of road condition measures with community expectations, specifically for local roads carrying low volumes of high-mass vehicles. Work to improve understanding of the interaction between heavy vehicle loading and pavements is in the early stages.

Many agencies have developed asset management manuals, detailed processes, and analytical tools that support the day-to-day management and planning of road-related assets; however, a protocol is in place to support harmonised modelling of road user costs among road agencies across Australia. The protocol recognises harmonisation as dynamic in nature, and allows for continuous improvement on a coordinated basis. The concept of road hierarchies (fitness for purpose) is entrenched among the major road agencies, and is spreading among smaller road agencies.

The Austroads document Integrated Asset Management Guidelines for Road Networks details a process for integrating all applicable asset management components - policy development, planning, plan execution, and verification - into a comprehensive planning framework. It defines Integrated Asset Management as "a process for ensuring the requirements of road agencies, road users and other stakeholders are clearly understood and integrated into an asset management framework that optimises the outcomes achieved from policy and investment decisions".

This Data Standard for Road Management and Investment in Australia and New Zealand has been developed in response to a need to standardise and harmonise data sets that support common road management and investment activities. Specifically, this Standard establishes a common understanding of the meaning or semantics of the data, to ensure correct and proper use and interpretation of the data by its stakeholders. The data specifications are specific to the data that is typically and routinely used for road management and investment purposes. It provides consistency in data definition and format. A Data Standard will assist with road management and investment activities including: asset and service performance assessment, performance benchmarking, road research, policy development, expenditure comparisons, funding approvals, supporting national reforms, national reporting, innovation, shared services, and inter-organisation communications.

This Standard is designed to support asset information management systems for data collection, finance, risk, and information. It is the product of comprehensive consultation in Australia and New Zealand across the road industry.

The Standard allows organisations to determine their desired level of sophistication with respect to both asset inventory recording and asset management planning and provides the relevant data specification in this regard. This approach is consistent with the fundamental principles of ISO 55000:2014 Management System – Asset Management, particularly regarding maximising ‘value’ from assets.

2 ASSET MANAGEMENT PROCESS

The existence of numerous standards on asset management indicates that it is a general process with wide applicability. The asset management process for buildings will be used as the basis for this section since buildings have a wider range of stakeholders and more inter-dependent systems.

2.1 Asset Management as a Process

In order to provide appropriate asset management methods there needs to be:

1. A definition of the service(s) required of the asset by the stakeholders;
2. A description of the asset;
3. Methods of assessment to ensure that the asset supports the required level of service in its current state, or to determine where the asset fails to meet the required level of service.

2.2 Stakeholders and Service Requirements

A wide range of stakeholders can be identified for all of the asset types considered within this report (Figure 5).

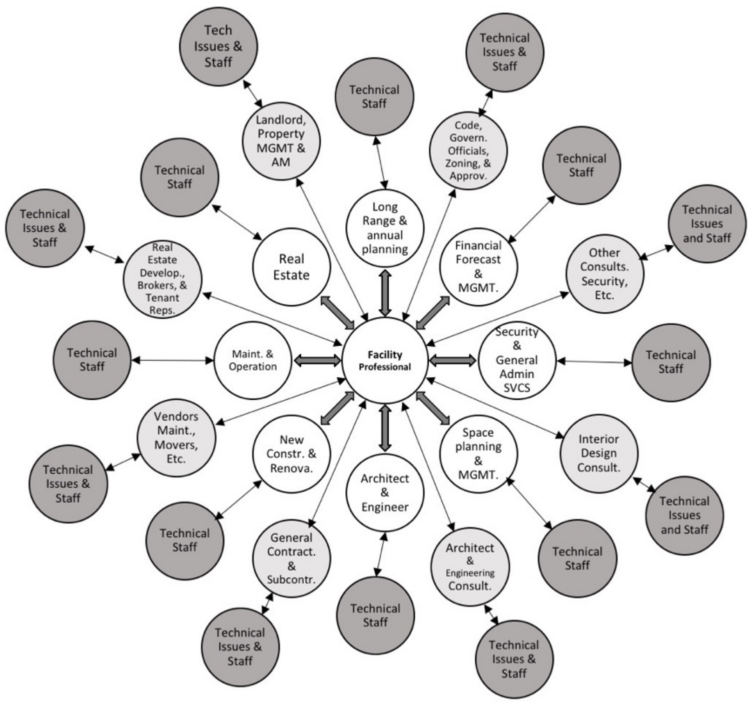

Figure 5: Asset Management Stakeholders for Buildings

Some stakeholders play significant roles across an asset portfolio (strategic), others play a role in identifying the need for new or modified assets (tactical), others control aspects of the use or maintenance of assets (operational), while a large group of "asset users" have no direct input to asset management processes other than the ability to register a complaint if the asset is not performing as expected. At each level the Plan, Do, Check, Act cycle (Figure 6) performs operations on the assets, which then needs to be captured within the supporting information systems.

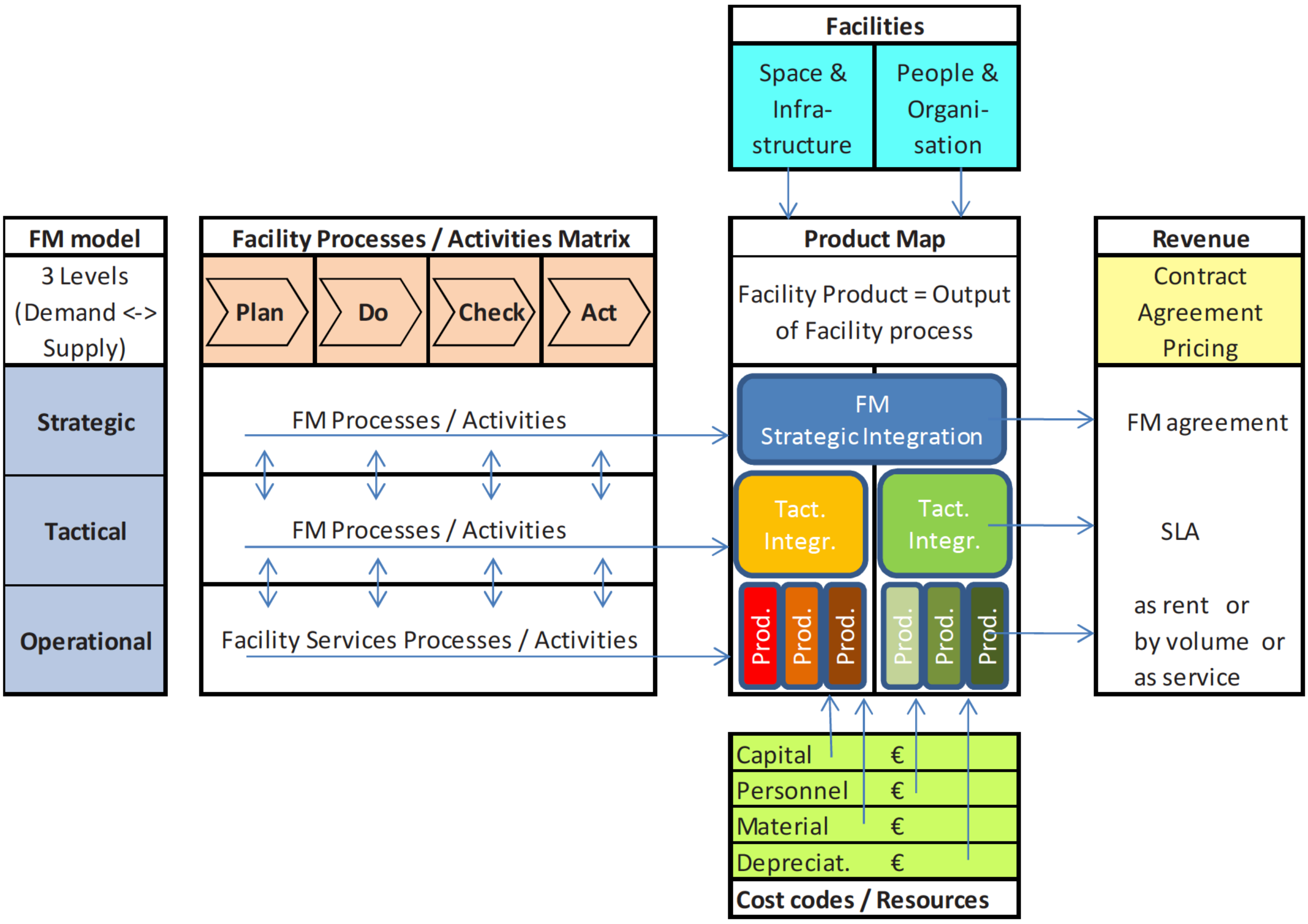

Figure 6: FM Relationship Model linking the basic FM Information Systems (BS EN 15221-4-2011)

The supporting asset management system needs to meet a wide range of corporate needs (Figure 7), ranging from the planning and maintenance processes carried out within the asset management/facility management department through to contract award and control and the financial systems that support the processing of payments. These will often be within separate management units and may be supported by different software systems. However, there needs to be some sort of interface between the various software systems if the entire organisation and the asset management functions are to be operated efficiently.

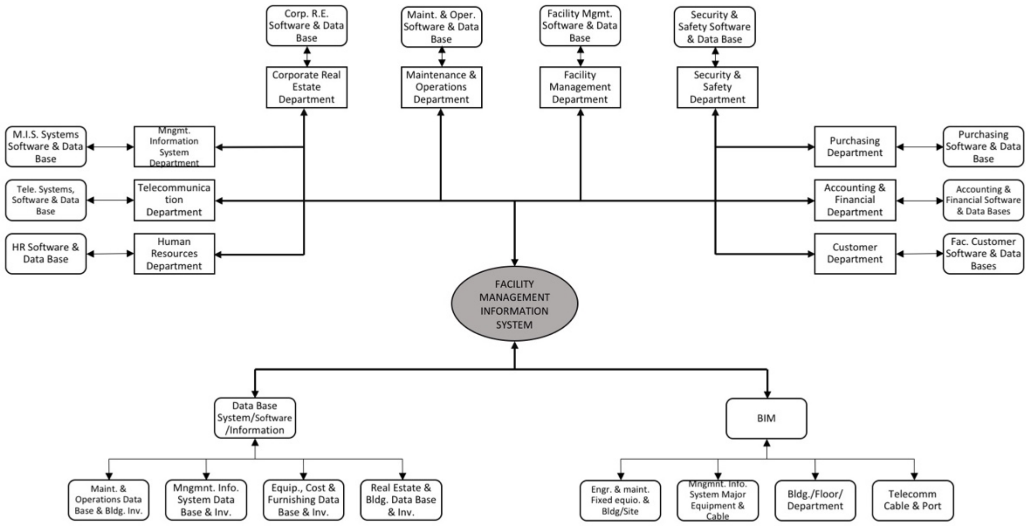

Figure 7: Information System in Organisational IT context

The technical activities within asset management will normally be within one department and will be serviced by a single software system (Figure 8).

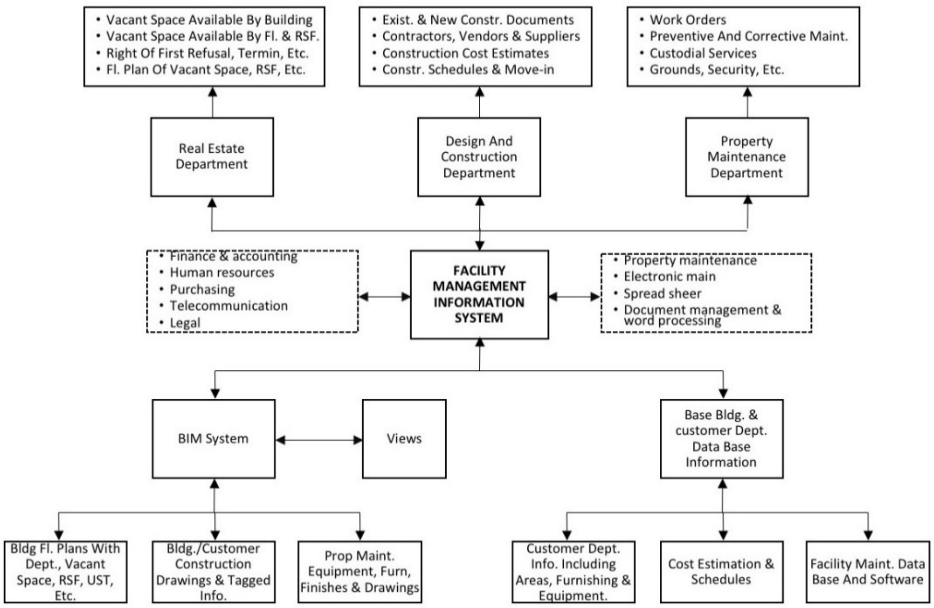

Figure 8: Asset Management Information System within Asset Management Department (Source: City of Port Adelaide Enfield, 2014)

2.3 Operations and Maintenance

Operation activities and costs are those which are required to run an asset (e.g. electrical charges for street lighting and costs for sweeping roads). Maintenance is the regular on-going work that is necessary to keep assets operating, including instances where portions of the asset fail and need immediate repair to make the asset operational again. The overall operations and maintenance strategy is intended to retain the current levels of service and mitigate risk while minimising cost.

The organisation will operate and maintain assets to provide the defined level of service to approved budgets in the most cost-efficient manner. The operation and maintenance activities include (City of Port Adelaide Enfield, 2014):

- Scheduling operational activities to deliver the defined level of service in the most efficient manner.
- Undertaking maintenance activities through a planned maintenance system to reduce maintenance costs and improve maintenance outcomes. Undertake cost-benefit analysis to determine the most cost-effective split between planned and unplanned maintenance activities.
- Maintain a current infrastructure risk register for assets and present service risks associated with providing services from infrastructure assets and reporting Very High and High risks and residual risks after treatment to management and Council.
- Review current and required skills base and implement workforce training and development to meet required operations and maintenance needs.
- Review asset utilisation to identify underutilised assets and appropriate remedies, and over utilised assets and customer demand management options.
- Maintain a current hierarchy of critical assets and required operations and maintenance activities.
- Develop and regularly review appropriate emergency response capability.
- Review management of operations and maintenance activities to ensure Council is obtaining best value for resources used.
- Council continue with Unmaintained Roads Policy and Unmaintained Road Safety Program and review it annually to ensure its currency.
- Council continues with one grade per year on all unsealed roads unless additional funds are available. For additional risk on unsealed roads, use money available for re-sheeting to be used for grading.

The overall operations and maintenance strategy is intended to retain the current levels of service and mitigate risk while minimising cost. Activities designed to ensure sufficient utilisation of the asset. These are the regular tasks that are undertaken to ensure the assets achieve their service potential. Operations strategies include activities such as inspections and system monitoring. Maintenance strategies are designed to enable existing assets to operate to their service potential over their useful life. There are two types of maintenance:

- Unplanned Maintenance: Work carried out in response to reported problems.
- Planned Maintenance: Work carried out to a pre-determined schedule or programmed as a result of needs identified during inspection.

All materials used in the maintenance and repair of assets will comply with all relevant technical standards. All maintenance work undertaken should be in accordance with the asset owner’s specifications and standards and relevant regulations.

3 ASSET DATA EXCHANGE STANDARDS

3.1 Introduction

Digital Asset Information Model is dependent on strong information and data exchange capabilities, allowing interoperability of information generated throughout the project lifecycle. This section will review the most widely used open data exchange standards in both building and transportation infrastructure industries.

3.2 IFC

The IFC (Industry Foundation Classes) (IFC 2018) is a data schema developed by buildingSMART to support the representation of buildings and the exchange of this information between different pieces of software in a vendor neutral way. While the development of the IFCs commenced in 1995, its heritage in the STEP (ISO10303) standards takes its development back into the 1980's.

IFC contains a data schema which can be represented as an EXPRESS or as an XML schema specification. The EXPRESS schema definition is the source, and the XML schema definition is generated from the EXPRESS schema according to the mapping rules defined in ISO 10303-28. IFC takes the object-oriented approach, in which data are organised into a hierarchy of classes. The data schema architecture of IFC defines four conceptual layers, each individual schema is assigned to exactly one conceptual layer. Figure 9 shows the schema architecture.

The IFC4 model contains 766 entities (object definitions) and is an extensible schema through the use of proxy objects to support the addition of objects that are not already part of the model. A Pset (property set) mechanism also allows additional properties to be added to the existing definitions. The IFC model is broken up into a number of layers and modules. This increases the ease of understanding this large model and also provides some focus for discipline specific information (Figure 9)

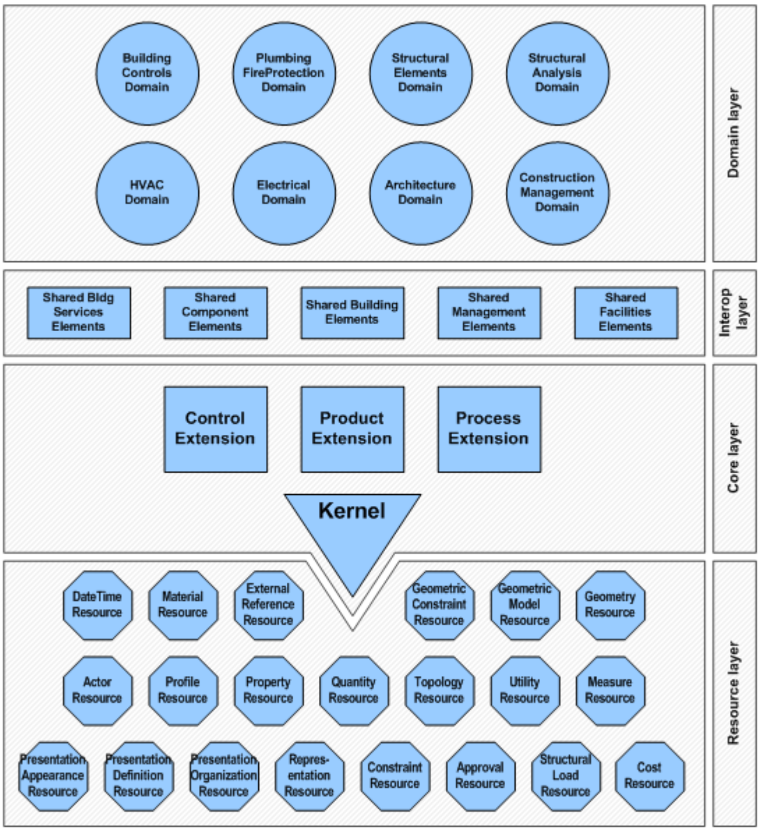

Figure 9: IFC4 Data Schema Architecture with Conceptual Layers (IFC, 2018)

In IFC specification, a Model View Definition (MVD) represents a subset of the data schema and referenced data. In order to support recognized workflows in the construction or facility management industry sector, a specific MVD is defined. In addition, data exchange requirements for software applications are identified by each recognised workflow. Conforming software applications need to identity the model view definition they conform to. Therefore, buildingSMART International has published official model view definitions (MVD) to support a well-defined subset of the data schema and referenced data.

The major focus of development of the IFC model has been on buildings. These can be represented within the IFC model to a high level of comprehensiveness and detail. Site works and infrastructure are not currently well supported, although there are a number of projects underway through buildingSMART that are adding the base representations required to handle projects dispersed over long distances and also to handle bridges and roads.

One method of exchanging IFC-based information is through an IFC file, compliant with ISO10303:21. The structure of an IFC exchange is based on a containment hierarchy, with ifcProject as the required top level construct, with optional ifcSite(s) containing ifcBuilding(s), containing ifcBuildingStorey(s), containing ifcSpace(s) (Figure 10). Building components, such as walls, doors, furniture, etc. are then contained within one of the above entities.

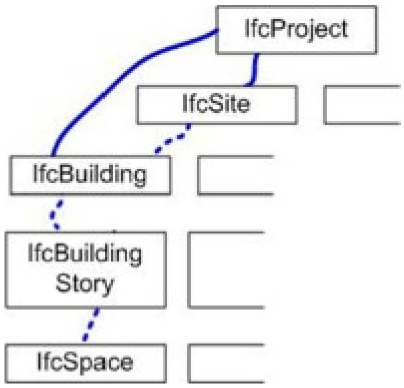

Figure 10: IFC Containment Hierarchy

3.3 COBie

The COBie (Construction Operations Building Information Exchange) (East 2016) standard allows the owner/operator of a facility to define what information is required to perform the asset management functions. Ideally, this would be provided to the team that will construct the facility before construction commences. Figure 11 shows the generic COBie Data Structure.

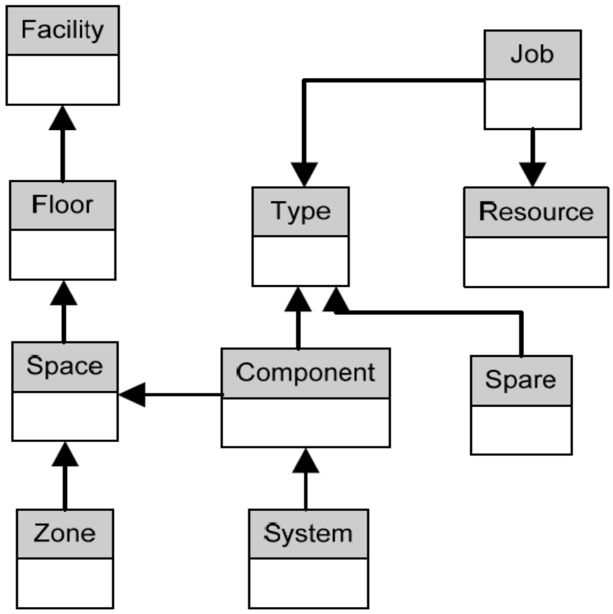

Figure 11: Generic COBie Data Structure (Entity - Relationship Diagram)

For new facilities, this information is provided to the design/construction team prior to project commencement and compliance with the "COBie" approach is one of the contracted project deliverables. It is then up to the design/construction team to decide who is responsible for providing particular pieces of information.

COBie defines a staged approach, with data drops at these stages of a new project:

1. Design deliverables at 35%;
2. Construction documents on completion of the construction documents;
3. Construction deliverables at occupancy;
4. Complete construction deliverables at financial completion.

The intention of this staged approach is to ensure that the required information is provided by the personnel responsible for installing the relevant building components.

The key components of COBie are:

1. Standardised object (BIM) model:
    a. Definitions of physical objects and attributes.
    b. Location containment hierarchy (i.e. site -> building -> storey -> room).
    c. Ability to define systems – provide support for service provision.
    d. Model View Definition – computer interpretable format for data exchange.
    e. Industry Delivery Manual – instruction manual to guide the data gathering and sharing process (guidance for humans).

2. Definition of asset capture process and deliverables:
    a. When data should be captured.
    b. Process for deciding who captures it.
    c. Technology to support data capture.

Items (a) – (c) are normally provided by an IFC model.

A Model View Definition (d) has already been prepared for COBie (US) (http://docs.buildingsmartalliance.org/MVD_COBIE/).

In its most basic form, COBie can be used just by filling in cells in a spreadsheet which can then be uploaded into an appropriate database. Alternatively, more high technology methods of data capture can be used.

Besides the information describing the facility and its components, the following information is also captured:

1. Maintenance data
    a. Warranties
    b. Spare/replacement parts
    c. Preventative maintenance tasks
    d. Resources
2. Operations
    a. Start-up/shut down procedures
    b. Trouble shooting procedures
3. Assets (including financial)
    a. Space measurements
    b. Fixed or moveable property
    c. Space-function capabilities

The use of COBie for existing facilities is obviously a bit more problematic than for new buildings. The same information needs to be collected, where possible, by a thorough audit of the facility.

There is no explicit requirement in COBie for a BIM model of the target facility so that creating a BIM model of an existing facility will be beneficial but not a requirement.

3.4 IFC for Building and Housing

The IFC model was originally intended to only support buildings. Currently, building models are well supported within the building itself, but external and site works are less well supported. IFC 2.0 was released in 2000 and was the first version that had strong software vendor support. Previous versions were used as proof-of-concept and for demonstrations. IFC 2x2 was the next significant release, with IFC2x3 being the most strongly supported current release. IFC4 is now gaining significant penetration, but with long delivery times on building projects, IFC 2x3 will still be used for the next few years (IFC 2018).

All of the major software houses provide good support for IFC for housing and building projects, with penetration into significant industry projects, such as the Sunshine Coast Hospital and the Queens Wharf project.

There are three different kinds of COBie format: the IFC STEP Physical File Format (IFC SPFF), ifcXML and SpreadsheetML. The latter is the well-known format used by Microsoft Excel™ and also some other spreadsheet tools including OpenOffice. If COBie is used in a long-term project, COBie type data will be expected to be held in a DataBase Management System (DBMS) which provides a way that spreadsheets or other view reports could be extracted from. Although the spreadsheets would be written and read by software in the process, the reason SpreadsheetML was chosen by most people was that it is relatively easier to read by humans between the three.

A COBie workbook contains information about a single facility. Additionally, the COBie Responsibility Matrix lays out the spreadsheet schema and twenty worksheets are spread out from the schema as shown in Table 1.

Table 1: Cobie Spreadsheet Schema (East, 2016)

Sheet Name	Description
INSTRUCTION	Header information and instructions
CONTACT	Information about people who create COBie information
FACILITY	Project, site, and building (IfcProject, IfcSite, IfcBuilding) - a distinct operational unit, along with the project and site details.
FLOOR	Vertical levels and exterior areas (IfcBuildingStorey) - a primary spatial subdivision
SPACE	Spaces on a floor (IfcSpace) - a location for activity such as use, inspection or maintenance.
ZONE	Sets of spaces sharing a specific attribute (IfcSpatialZone)
TYPE	Types of equipment, products, and materials (IfcTypeObject)
COMPONENT	Individually named or schedule items (IfcProduct)
SYSTEM	Sets of components providing a service (IfcSystem)
ASSEMBLY	Constituents for TYPES, COMPONENTS (IfcRelAggregates)
CONNECTION	Logical connections between COMPONENTS (IfcRelConnectsElements)
SPARE	Onsite and replacement parts (IfcConstructionProductResource)
RESOURCE	Required materials, tools, and training (IfcConstructionEquipmentResource)
JOB	PM, safety, and other operational plans (IfcTask)
IMPACT	Economic, environmental and social Impacts at various stages in the life cycle (IfcProperty)
DOCUMENT	All applicable document references (IfcDocumentInformation)
ATTRIBUTE	Properties of referenced item (IfcProperty)
COORDINATE	Spatial locations in box, line, or point format for FLOOR, SPACE or COMPONENT (IfcCartesianPoint)
ISSUE	Other issues remaining at handover (IfcApproval)
PICKLISTS	Fixed enumerations and customizable code lists (IfcClassificationReference)

Columns within each spreadsheet are pre-defined. They are colour-coded and colours stand for specific information like whether the column content is required, a reference to another sheet or pick list, an external reference, if specified as required, or secondary information when preparing product data. According to the example spreadsheets, other specific data like regional, owner, or product can be added as new columns to the right of standard template columns. However, information in supplementary columns will not be checked by the standard quality assurance programs.

3.5 COBie for Building and Housing

The COBie standard is already in use internationally across housing and buildings, with strong support from the major relevant software vendors. The use of COBie is described in section 3.3 above. Consequently, it is a strong recommendation that the COBie approach be used as the starting point for housing and buildings in this project.

COBie data can be checked within the source software before export (Figure 12).

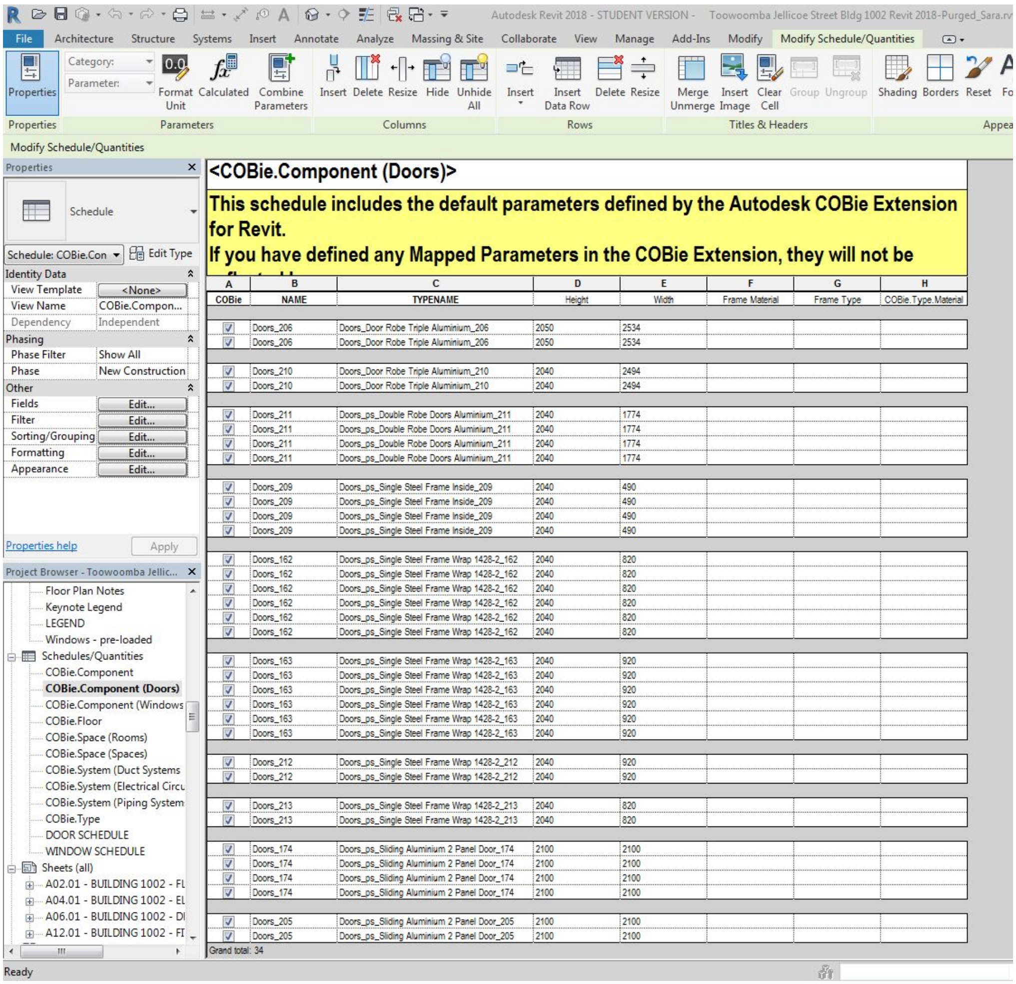

Figure 12: COBie Support within BIM Software

The information can also be filtered on export (Figure 13).

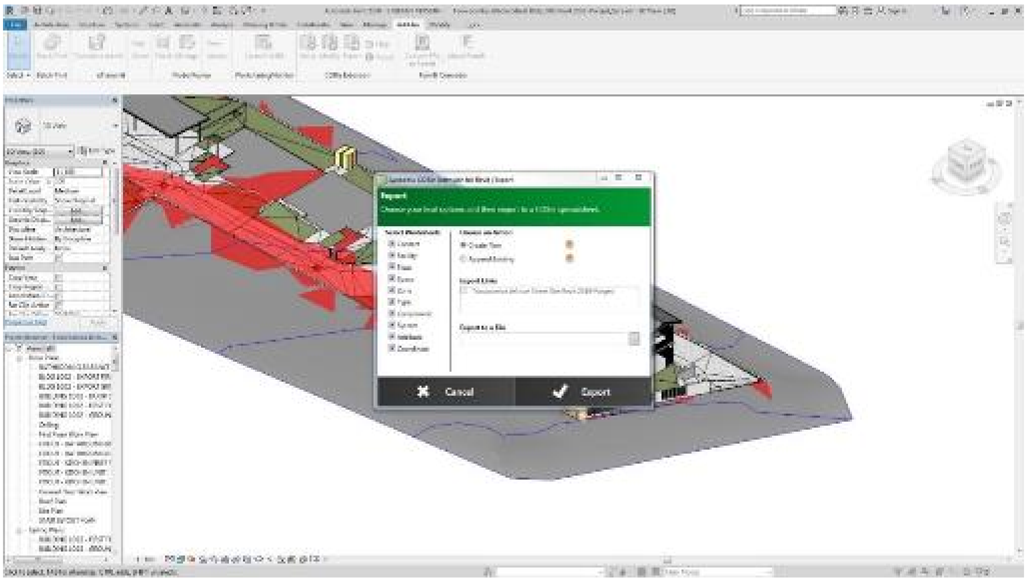

Figure 13: Exporting COBie Data

The basic COBie definitions can be defined in a spreadsheet (Figure 14). The General Services Administration (GSA) in the USA recommends a minimum set of COBie attributes. These are listed in APPENDIX B - Minimum Attributes for COBie Data.

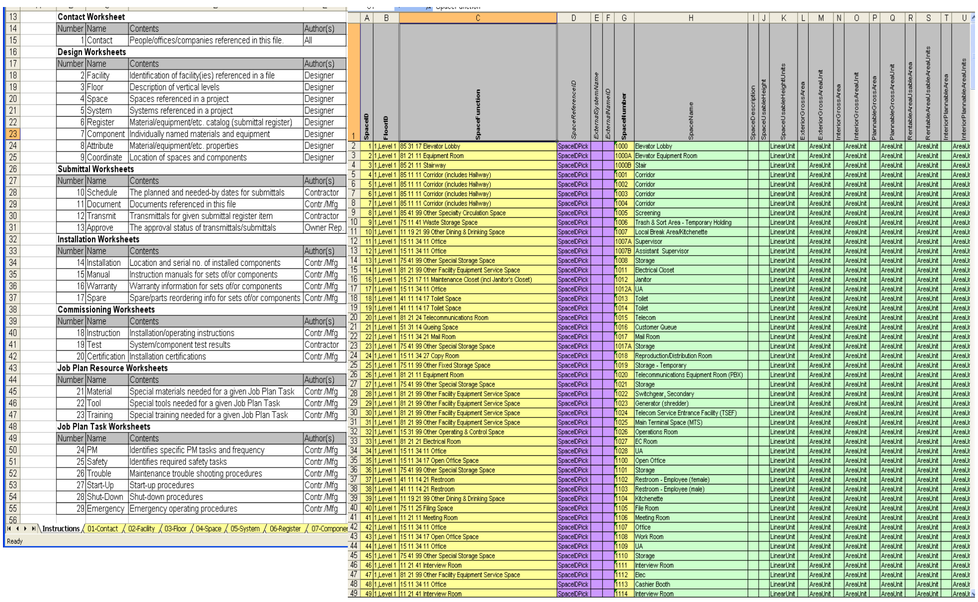

Figure 14: COBie Data Spreadsheet

3.6 LandXML/LandInfra/InfraGML for Transportation Infrastructure

Land and Infrastructure Conceptual Model Standard (LandInfra) is an OGC standard which defines concepts for providing and understanding information about land and civil engineering infrastructure facilities. Anticipated subject areas include facilities, projects, alignment, road, railway, survey, land features, land division, and “wet” infrastructure (storm drainage, wastewater, and water distribution systems). The initial release of this standard is targeted to support all of these except wet infrastructure.

The concepts in LandInfra are formally using case driven subset of LandXML functionality, but supported by a UML (Unified Modeling Language) diagrams. Additionally, the standard covers various subject areas defined by so called Requirement Classes (RCs), which mandate what the subsequent encodings must support in order to claim conformance to LandInfra. Each requirement class (RC) in RCs has a corresponding

Conformance Class which explains how the encoding is to be tested for conformance. The overall structure of LandInfra requirements classes is shown in Figure 15 .

“Core Requirements Class” is the most important part in LandInfra. It contains requirements which must be supported by all other subject area-specific RCs. This is also the only mandatory InfraGML RC that every application claiming conformance to InfraGML must support it. The rest of the RCs should be considered base on the scope of the application. It’s not necessary to comply with all of the RCs except the project is involved in all of those categories.

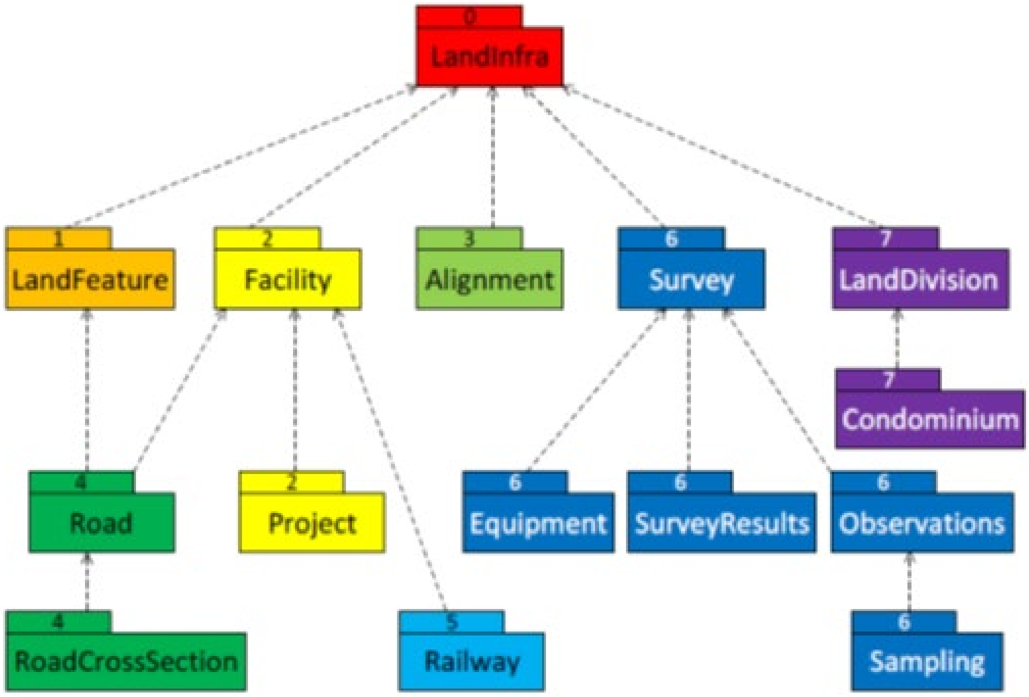

Figure 15: LandInfra Requirements Classes grouped into InfraGML Parts

The target audience of LandInfra spans civil engineering (e.g., road and rail), surveying, land parcel, facility and asset management, and government information communities. It is applicable throughout the entire facility lifecycle, including planning, design, construction, operations, maintenance, and removal. It represents a seminal venture into GIS-CAD-BIM integration.

Furthermore, the OGC InfraGML Encoding Standard presents the implementation-dependent, GML encoding of concepts supporting facilities specified in the OGC LandInfra. It builds upon GML3.2 and 3.3 foundation and follows the OGC Modular Specification for extensibility. Because of the breadth of LandInfra, its subject areas are divided into separate RCs. This InfraGML encoding similarly is divided into RCs which are then grouped into Parts. A Part may address multiple LandInfra RCs but each RC is addressed in a single part. The structural relationship between Landinfra and infraGML is shown in Table 2.

Table 2: Structure relationship between LandInfra and InfraGML

n	InfraGML part name
0	LandInfra Core
1	LandInfra LandFeatures
2	LandInfra Facilities and Projects
3	LandInfra Alignments
4	LandInfra Roads
5	LandInfra Railways
6	LandInfra Survey
7	LandInfra Land Division

In order to conform to this OGC encoding standard, a standardisation target shall choose to implement the core conformance class and any of the other conformance classes with their dependencies. Conformance classes are based on Requirements Classes which are specified in this and possibly other Parts of the InfraGML standard.

Developers can use InfraGML to implement software and services that enable users of diverse technologies and vendor platforms to efficiently exchange information about land and civil engineering infrastructure facilities.

3.7 IFC for Transportation Infrastructure

3.7.1 IFC Alignment

In terms of the implementing of IFC on C/I, P6 "IFC Alignment" project is the first buildingSMART “IFC for Infrastructure” extension project. This project provides the data model for 3D and 2D alignment information mainly for spatial location of infrastructure assets and further being a baseline for projects like IFC-Bridge and IFC-Road.

There is a conceptual model for IFC alignment which is developed based on the analysis of the processes in linear infrastructure and a detailed information requirement breakdown which categorizes all information items into three types, mandatory, optional and derived. As IFC Alignment is a description of road and rail alignments, the model is based on the well-established approach of aligning which contains vertical (gradient) and horizontal alignments. A general structure of alignment information in the IFC4 schema is shown as Figure 16.

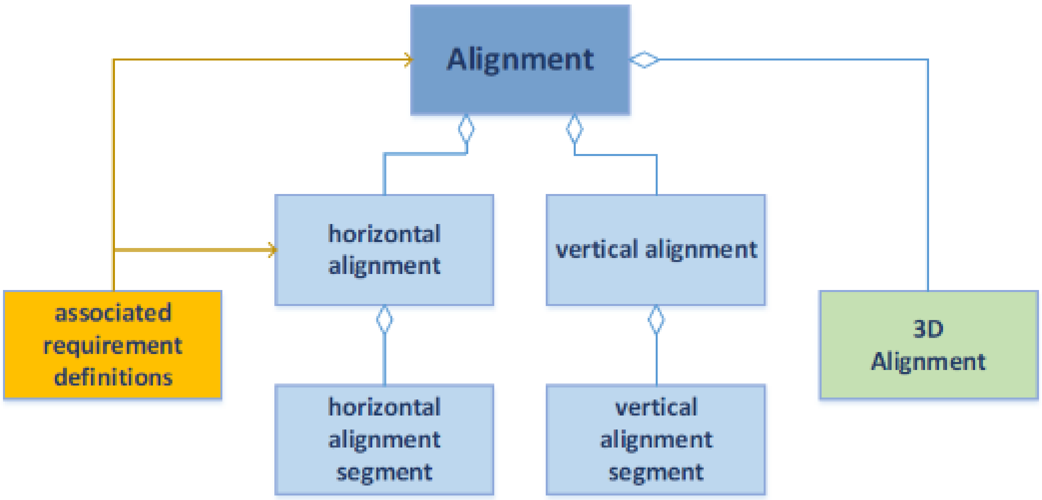

Figure 16: General Structure of Alignment Information

In this schema, the new IfcAlignment class is the key element. IfcAlignment references the horizontal alignment (IfcAlignment2DHorizontal) and the vertical alignment (IfcAlignment2DVertical). The horizontal alignment itself comprises the alignment elements line (IfcLineSegment2D), arc (IfcCircularArcSegment2D) and clothoid (IfcClothoidalArcSegment2D). Apart from the clothoid, no other transition curve types are currently contained in this standard. However, newly developed IFC Road and IFC Rail in the future may introduce some transition curve types such as the Bloss curve.

Elements in horizontal alignment are sharing a common subset of data attributes. Therefore, a common base class called IfcCurveSegment2DHorizontal was created. It comprises common data attributes such as start position, start direction and segment length which are needed by the elements. With these three attributes, other attributes such as end point, end direction, start distance along and end distance along can be calculated. The class IfcAlignment2DHorizontal itself holds an ordered list of ifcAlignment2DHorizontalSegment elements, which each reference a concrete alignment element (line, arc or clothoid).

Vertical alignment follows the similar approach with the horizontal one as well. Parabolas (IfcAlignment2DVerSegCircularArc), arcs (IfcAlignment2DVerSegParabolicArc) and lines (IfcAlignment2DVerSegLine) compose the vertical alignment. These three elements are derived from the class IfcAlignment2DVerticalSegment, thus they can share common properties like start gradient or start height of an element. Correspondingly, an ordered list of the alignment elements mentioned is managed by the class IfcAlignment2DVertical. This class is referenced in proper order by the class IfcAlignment.

Upon the whole, IfcAlignment references a horizontal alignment and a vertical alignment. The horizontal alignment elements are defined in a normally xy-space while the vertical alignment elements are defined in a space which assigns x to be the current station (distance along the horizontal alignment) and y to be the corresponding height (elevation) value at this station. Figure 17 shows how a 3D alignment can be derived from the combination of a horizontal and vertical alignment.

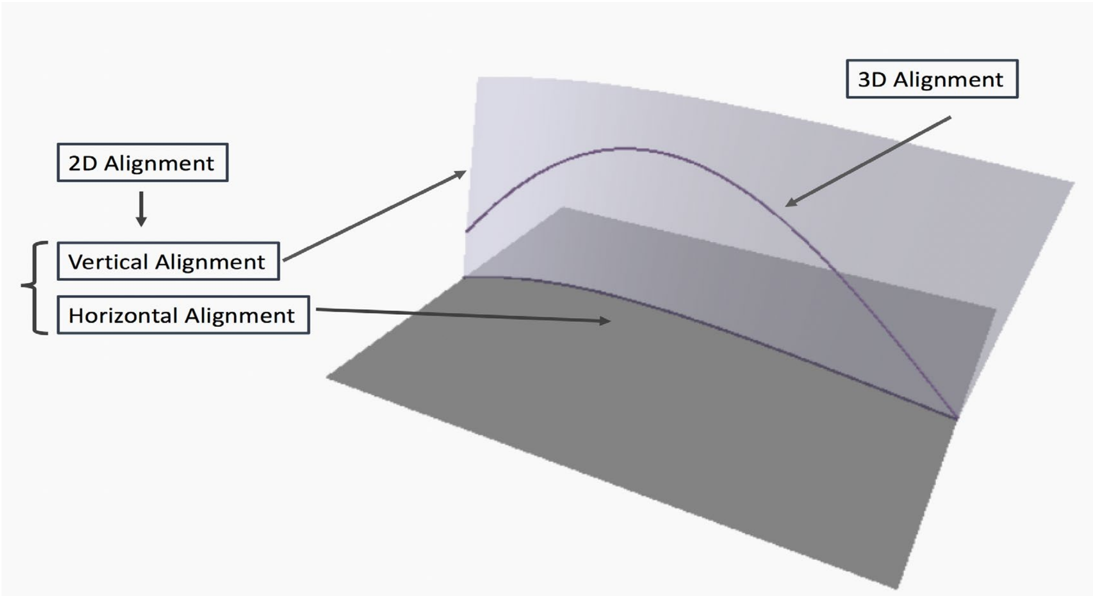

Figure 17: A 3D Alignment Combination from the Horizontal and Vertical Alignment

Main achievements of the IFC Alignment 1.0 are:

- Ability to exchange alignment information from planning to design, to construction, and finally to asset management phase.
- Ability to link alignment information to other project information such as cross sections and full 3D geometry of construction elements (realized by upcoming IFC-Bridge and IFC-Road projects).
- Ability to query alignment information providing data such as linear referencing for positioning.
- Ability to allow open data access of alignment information from asset management databases.
- Ability to map IFC alignment models to InfraGML (developed by OGC), and LandXML (latest InfraBIM version from buildingSMART Finland).
-

This project developed the specification to enhance the current IFC4 data standard, including process definition, exchange requirements, data model, and model view definition with samples which would be helpful on the data exchange of the C/I project.

3.7.2 IFC Road

The two most important domains in infrastructure which had been identified by a new committee called Infrastructure Room of BuildingSMART had been Bridges and Roads. However, these two project are still currently in development phase.

While the IFC Road project looks at the overall life-cycle of road facilities, the main focus is the handover of detailed design to construction and to the governing agencies. The terrain model, the civil elements organised in the various structures, and subsidiary objects shall all be created as 3D objects and enriched by predefined property data. IFC-Road schema defines the structure for these object definitions and it includes reference data in terms of property set definitions.

The data schema definition of road includes (Figure 18):

- Spatial structure: spatial structure breakdown suitable for road constructions
  - Local engineering and geospatial coordinate reference system
  - Alignment for linear placement and positioning
- Physical structures: road facilities, earthwork, civil common, culvert, retaining wall, drainage, and subsidiary facilities

    - Assemblies to group elements into the next higher facility level
    - Shapes to describe complex road elements

- Properties: common properties of road project suitable for the level of information "design to operation phase", suggesting unique properties for each element
- Earthwork model: an original terrain model for the construction site, cut and fill entities as a volumetric shape object, other terrain models

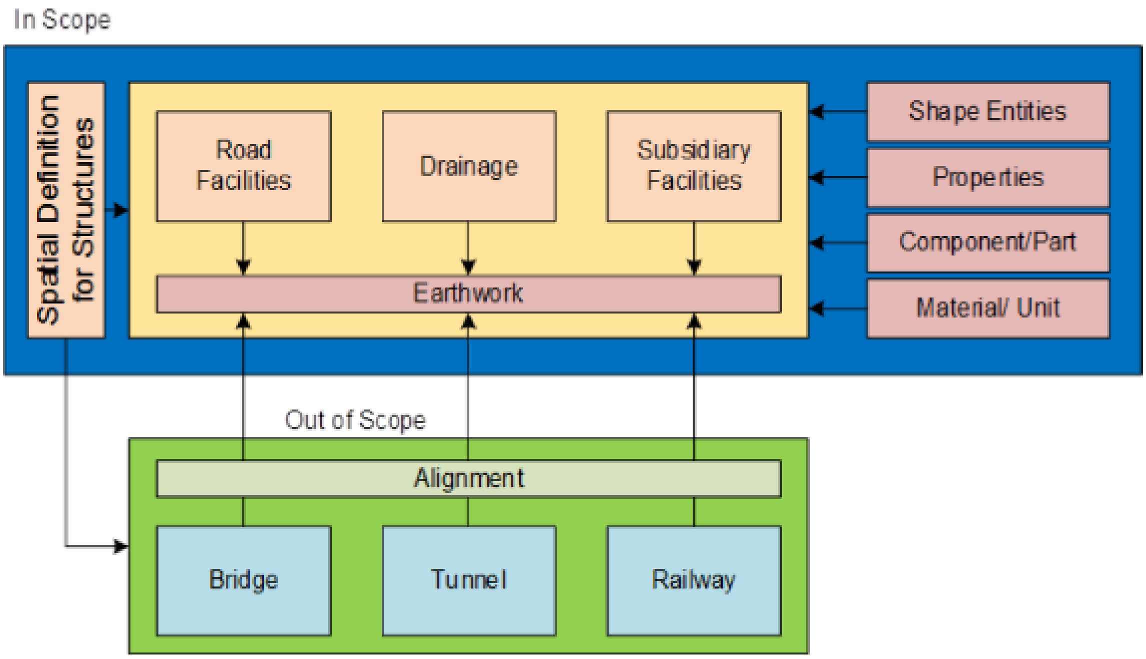

Figure 18: New Scope Definition of IFC-Road (Source: KICT)

The main scope of the IFC Road project is to extend product data model of road facilities with earthwork enabling open data access based on IFC4 (ISO16739) schema in order to secure interoperability in delivering the as-built design model to government. In this project, the critical facility scope includes spatial structure related to road, roadway with cross-section, earthwork with cut & fill, drainage facilities.

3.7.3 IFC Bridge

IFC Bridge is an extension of the IFC data model for exchanging bridge models based on IFC. It contains a rich set of building element types required for describing bridges. The means of geometric representation are adapted directly from IFC. The geometric form of the bridge superstructure element is represented by prismatic segments ("IfcBridgePrismatic-Element"). In addition, IFC Bridge includes entities for the definition of roadway tracks, such as IFCClothoid.

Early IFC Bridge extension had been based on the IFC2x3 platform and dealt with the bridge specific structures and elements. One important, but difficult task had been the positioning and derivation of shape for the elements along the reference line of the bridge. However, while the extension is currently upgraded to IFC4, this part and other parts like dealing with the bridge reference line are replaced by the new IFC Alignment standard. Therefore, the most difficult task now is to describe the shape of bridge elements along the alignment, using a sub section of the alignment as a directrix for sweeping operation.

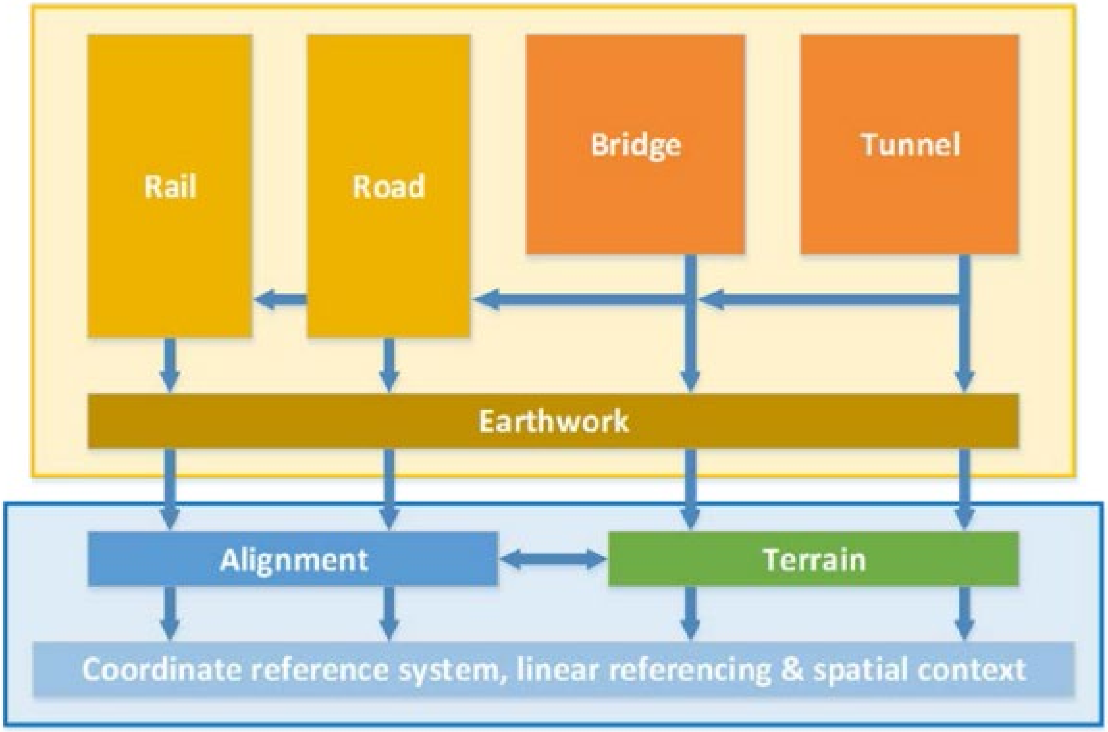

Figure 19: Main Dependencies between Selected Infrastructure Areas

Certainly, among all infrastructure works, bridges are among the most complex and have many structural elements with considerable commonalities to building elements. Therefore, the extension of the exiting IFC data schema, primarily focusing on buildings to the inclusion of bridges would be a natural evolution. The main dependencies among IfcAlignment, IfcRoad, IfcBridge, IfcRail, and IfcTunnel are shown in Figure 19.

3.8 COBie for Transportation Infrastructure

3.8.1 Introduction

There are some research studies that aim to implement COBie in Commercial/Industrial (C/I) projects, such as rail and subway stations. Unlike the components in buildings, most of objects in C/I projects tend to be continuous like roads, rather than discrete like windows and doors. Attributes of these continuous objects usually vary in value along the object since the location of these objects is basically via linear referencing, geospatial coordinates or feature geometries. In view of these distinctions, appropriate adjustment must be applied in COBie's data structure.

3.8.2 Data Structure

Although COBie framework is designed for buildings, it is probable to find a way to support C/I project using the existing COBie entity relationship structure shown in **Error! Reference source not found.**Figure 11.

Nevertheless, the structure mentioned above is still from original version of COBie which is mainly for buildings. As for C/I project, there are some parts recommended to slightly change in terms of the schema to fix the problem that it does not support the asset management perspective voiced by some professionals.

The recommendation considered would be in two different ways. One of which is to move the Columns of MANUFACTURER and MODELNUMBER from TYPE to COMPONENT; another would be being relabelled as EXAMPLEMANUFACTURER and EXAMPLEMODEL. EQUIPMENT (and perhaps CAST-IN-PLACE) needs to be added, preferably as part of a new Operate package. Original Serial number in COMPONENT should be moved to EQUIPMENT. Then COMPONENT truly does become the asset requirement and EQUIPMENT and CAST-IN-PLACE are the fulfilment of that requirement.

4 ASSET CLASSIFICATION SYSTEM

4.1 Asset Classification for Building and Housing

In the field of asset management there have been many different approaches to the definition, structuring and allocation of costs. The differing relationships around cost cannot be accommodated within one single structure without compromise or repetition (EN 15221-4:2011). EN 15221 defines generic methods of structuring information to support hierarchical classifications. These improve the ability to combine, analyse and present information to end users. The ISO 9000 definition of product is used to cover services, software and hardware.

EN15221 provides a standardised facility product map that supports:

- A uniform specification of services;
- Cost allocation and comparison;
- Consistent measurement of quality and performance;
- Benchmarking

The activities and facilities structures can be connected as a matrix. The addition of cost provides the third dimension, allowing these relationships to be represented as a cube (Figure 20).

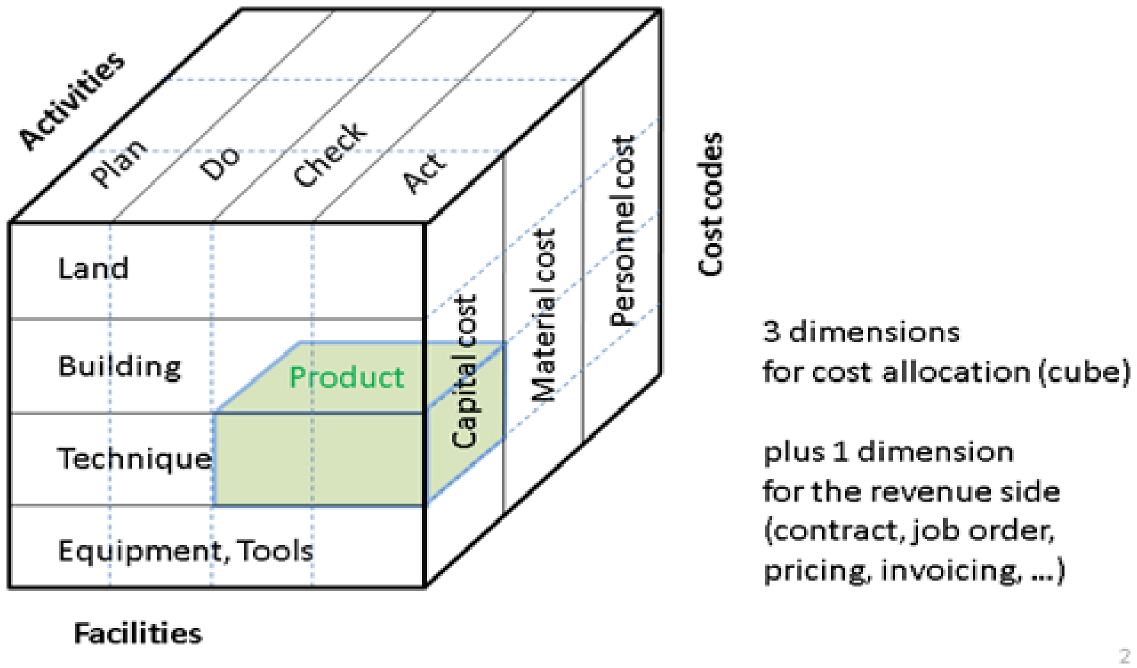

Figure 20: Relationship between the Three Independent Dimensions required to describe a product (BS EN 15221-4-2011)

There are a number of classification systems used within the housing and building sectors. Uniclass is used in the UK, while OmniClass is based in the USA. The details of these are described in Appendix A – Classification Systems for Buildings: OmniClass Table 23 – Products.

4.2 Overall Asset Classification System

The aim of Asset Classification System is to provide a single point of reference of asset discipline, asset class, asset function, asset type, and asset component for stakeholders involved in the planning, acquisition, operation, maintenance and disposal of assets. In this section, the overall asset classification system is illustrated to provide a global view of the system which could integrate assets in both building and transportation infrastructure domains. Then, asset classifications dedicated for building and transportation infrastructure respectively are discussed in the following subsections.

Each asset should be defined according to the asset classification system. Figure 21 illustrates the global view of the asset classification systems which contains an eight-level hierarchy. Buildings or transportation infrastructures, which are the two main focuses, could fit into the classification system in the "Asset Category" level.

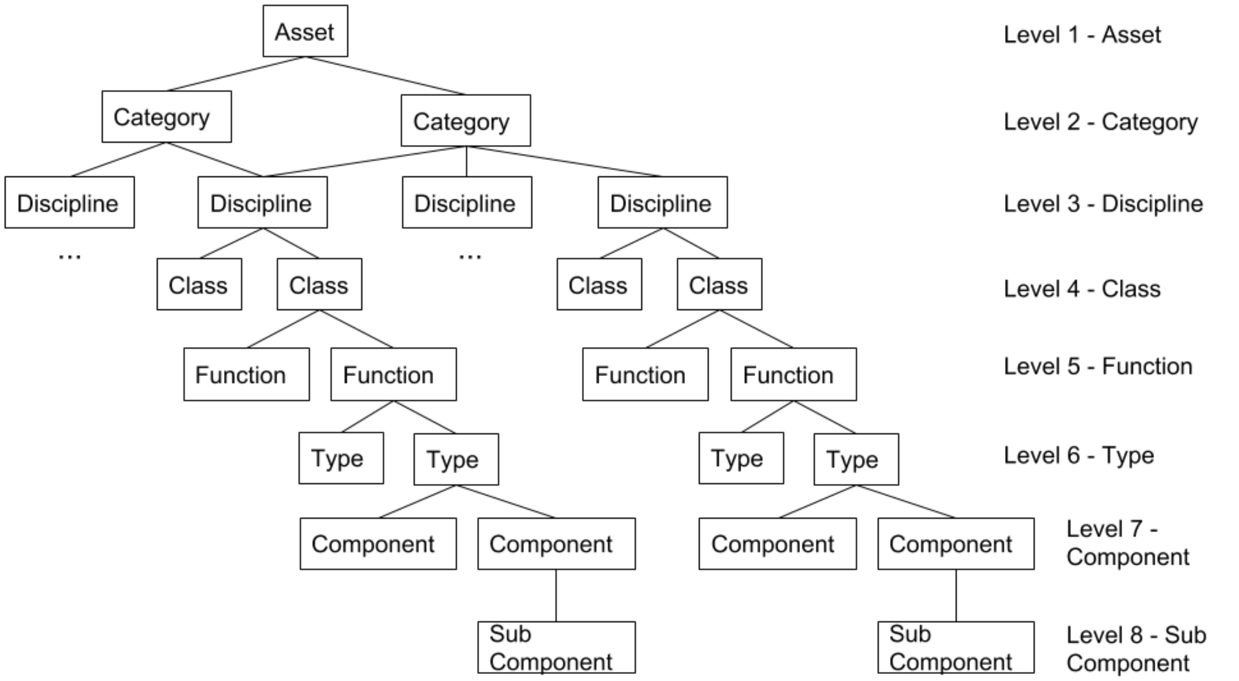

Figure 21: Asset Classification System Level 1 - level 8

4.2.1 Level 1 - Asset

The total assets in a city scale. The asset represents a grouping of categories.

4.2.2 Level 2 - Asset Category

The asset category represents a grouping of related disciplines; for example, office building, rail infrastructure, and road infrastructure.

4.2.3 Level 3 - Asset Discipline

The asset discipline represents a grouping of related asset classes; for example, civil and structures.

4.2.4 Level 4 - Asset Class

The asset class shall be used to group one or more asset functions into a logical group. The asset class shall be a separate identifier in the asset register.

The asset class shall be the primary grouping of similar assets related to the asset discipline; for example, bridges.

Asset class shall define the grouping of asset functions.

4.2.5 Level 5 - Asset Function

An asset function shall be associated with an asset class; for example, overbridges.

The asset function shall be used to group one or more asset types that perform the same function. The asset function shall be a separate identifier in the asset register. An asset function shall be associated with one asset class.

Asset function shall define the following:

- grouping of asset types
- non-graphical data attributes required to be captured and managed, including the physical data, functional data, operational data, organisational data and the asset condition
- standard for the associated data attributes, including the name, type, format, unit of measure, accuracy and value range (minimum and maximum)

4.2.6 Level 6 - Asset Type

Asset types consist of groups of assets that have common characteristics which distinguish them from those assets that perform the same asset function.

Asset types shall not include differences in material construction or manufacturer. An asset type shall have unique characteristics that distinguish them from other asset types within an asset function. This detail shall be defined by the asset specification also known as the technical maintenance code (TMC) and contained in the relevant asset attribute metadata.

4.2.7 Level 7 & 8 - Asset Component and Sub-components

Component parts shall be related to the asset type, which defines the build of the asset. Sub-component parts are related to the component. The sub component may be used as a positional reference; for example, left, right, top, middle, bottom and number 1.

Components and sub-components can vary across the different asset types; for example, different signal asset types can have different component builds.

4.3 Asset Classification for Transportation Infrastructure

Asset classifications related to transportation infrastructure are reviewed to serve as a guideline on how assets should be codified in the customised asset classification system.

4.3.1 Asset Classification System used by TfNSW

The structure of Asset Classification System (ACS) used by TfNSW contains four levels (Figure 22) including asset discipline, asset class, asset function, and asset type (TfNSW 2019a).

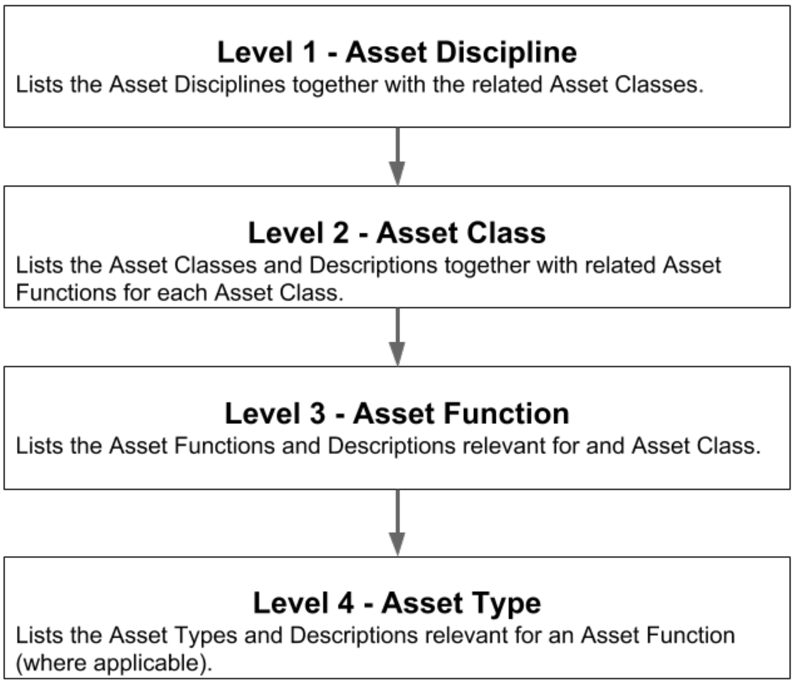

Figure 22: Asset Classification Breakdown (TfNSW, 2019a)

- Level 1 - Asset Discipline: Lists the Asset Disciplines together with the related Asset Classes, e.g. architecture & service, civil & structures, electrical, fleet, property, signalling & control, technology & telecommunications, and track.
- Level 2 - Asset Class: Lists the Asset Classes and Descriptions together with related Asset Functions for each Asset Class. Similarly, as ISO standard, more than one object class is classified in one Asset Class.
- Level 3 - Asset Function: Lists the Asset Functions and Descriptions relevant for an Asset Class, such as Complexes (e.g. road carriageway, waterway, bus fleet depot, quarry, land), Entities (e.g. building, footbridge, sea wall, jetty, bus, furry), Systems (e.g. air supply system, LV lighting system) and Products (e.g. air dryers, meters).
- Level 4 - Asset Type: Lists the Asset Types and Descriptions relevant for an Asset Function (where applicable). Namely, this level is only specified in some objects. There is no guideline to capture related information at this level which provides the flexibility to store information in this level.

In order to show this ACS system in practice, Figure 23 demonstrates a sample of “Architecture & Services” classification from level 1 to level 4.

This ACS object classes do not cover whole lifecycle of asset management. Specifically, activities from design, construction, operations, and maintenance till disposal of asset are not classified in the current ACS. Therefore, TfNSW indicates that a classification system which can be implemented in whole lifecycle should be considered in the future.

	A	B	C	D	E	F	G	H	I
1	Cnt	Disc L1	Discipline	Class L2	Class Description	Function L3	Function Description	Type L4	Type Description
2	1	AR	Architecture & Services	CA	Compressed Air Systems	AIRD	Air Dryer		
3	2	AR	Architecture & Services	CA	Compressed Air Systems	AIRM	Air Main		
4	3	AR	Architecture & Services	CA	Compressed Air Systems	AIRR	Air Receiver		
5	4	AR	Architecture & Services	CA	Compressed Air Systems	AIRS	Air Supply System (Facility)		
6	5	AR	Architecture & Services	CA	Compressed Air Systems	AUTO	Air Supply-Auto Drain		
7	6	AR	Architecture & Services	CA	Compressed Air Systems	COMP	Compressor		
8	7	AR	Architecture & Services	CA	Compressed Air Systems	EXPJ	Air Supply-Expansion Joint		
9	8	AR	Architecture & Services	CA	Compressed Air Systems	MANI	Air Supply-Air Manifold		
10	9	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	DBRD	Distribution Board	MN	Main
11	10	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	DBRD	Distribution Board	SU	Sub
12	11	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	ELEC	LV Electrical System (Facility)		
13	12	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	ERTH	Earthing		
14	13	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	GENR	Generator		
15	14	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	LGTF	Lighting System (Facility)	EM	Emergency
16	15	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	LGTF	Lighting System (Facility)	GE	General
17	16	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	METR	Meter	EL	Electricity
18	17	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	SPNL	Solar Panel		
19	18	AR	Architecture & Services	ES	LV Electrical & Lighting Systems	UPSY	UPS		
20	19	AR	Architecture & Services	FF	Furniture & Fixtures	ADVR	Advertising Board		
21	20	AR	Architecture & Services	FF	Furniture & Fixtures	ATMC	Auto Teller Machine		
22	21	AR	Architecture & Services	FF	Furniture & Fixtures	BINR	Rubbish Bin	SA	Safety
23	22	AR	Architecture & Services	FF	Furniture & Fixtures	BINR	Rubbish Bin	ST	Standard
24	23	AR	Architecture & Services	FF	Furniture & Fixtures	BKEL	Bicycle Locker		
25	24	AR	Architecture & Services	FF	Furniture & Fixtures	BKER	Bicycle Rack		
26	25	AR	Architecture & Services	FF	Furniture & Fixtures	BKES	Bicycle Shed		
27	26	AR	Architecture & Services	FF	Furniture & Fixtures	INFO	Information Board		
28	27	AR	Architecture & Services	FF	Furniture & Fixtures	PHNP	Payphone		
29	28	AR	Architecture & Services	FF	Furniture & Fixtures	PLTD	Platform Door	ED	Edge Doors
30	29	AR	Architecture & Services	FF	Furniture & Fixtures	PLTD	Platform Door	SD	Screen Doors
31	30	AR	Architecture & Services	FF	Furniture & Fixtures	POLE	Pole	FL	Flag
32	31	AR	Architecture & Services	FF	Furniture & Fixtures	POLE	Pole	LT	Light
33	32	AR	Architecture & Services	FF	Furniture & Fixtures	SEAT	Seat		
34	33	AR	Architecture & Services	FF	Furniture & Fixtures	SHWR	Shower Amenity		
35	34	AR	Architecture & Services	FF	Furniture & Fixtures	TOIL	Toilet	PU	Public
36	35	AR	Architecture & Services	FF	Furniture & Fixtures	TOIL	Toilet	ST	Staff

Figure 23: Sample of the Asset Classification System used by TfNSW (TfNSW, 2019a)

4.3.2 Asset Classification System used by Roads and Maritime Services (RMS)

There are 6 levels with 15 classes in the RMS asset classification system. All registered assets in RMS are categorised in six groups: Plant & Equipment (1005 of 2072 objects), Infrastructure System - Roads (964 of 2072 objects), Infrastructure System - Maritime (56 of 2072 objects), Land & Buildings (36 of 2072 objects), Service Concessions (8 of 2072 objects), and Intangibles (3 of 2072 objects). Most of the objects are from Infrastructure Systems Roads, Infrastructure Systems Maritime, Plant & Equipment and Land & Buildings. Groups are included in the classification structure. Table 3 shows the grouping structure of asset classification and its description.

Table 3: RMS Classification Structure

Level	Definition	Description	Example
Level 1 (Mandatory)	Asset Group	A group of assets having a similar business discipline in the operations of an entity.	Infrastructure Systems - Roads
Level 2 (Mandatory)	Asset Class	A group of assets having a similar nature in the operations of an entity, used specifically for financial management purposes.	Roadside
Level 3 (Mandatory)	Asset Function	A group of assets having a similar function in the operations of an entity.	Noise abatement
Level 4 (Mandatory)	Asset Type	A group of like assets which serve the same purpose. Asset Type is the level at which an individual asset is commonly	Noise walls

Level	Definition	Description	Example
		identified for financial reporting and management purposes.	
Level 5 (Desirable, typically required)	Asset Component	Specific parts of an asset having independent physical or functional identity and having specific attributes such as different life expectancy, maintenance regimes, risk or criticality.	Noise wall
Level 6 (Optional)	Asset Sub-Component	Smaller individual parts that make up a component part of an asset.	Post

4.3.3 Asset Classification System used by Austroads

Austroads is undertaking an ambitious project to establish a harmonised road asset data standard for use in Australia and New Zealand. The Road Metadata Standard Project has been initiated in response to requests from stakeholders who increasingly need to share data with other road management agencies but are frustrated by the lack of common data standards.

The Austroads Data Standard for Road Management and Investment in Australia and New Zealand is a current draft version of the Australian classification system for roads. This standard is an output-based specification that identifies a common reporting requirement for sharing data and to inform decision making. Six phases and their corresponding requirements are listed in Table 4 and the lifecycle of assets is illustrated in Figure 24.

Table 4: Austroads Classification Structure (Austroads, 2018)

Phase	Requirement	
Design	● Design criteria ● Construction Documentation ● Project cost estimate	● Ownership cost estimate ● Approved project
Construction	● Asset construction ● Asset commissioning ● As built documentation	● Asset maintenance plans ● Financial liabilities
Acquisition	● New or existing assets ● Asset commissioning	● Asset register ● Asset maintenance plans
Operations	● Operations ● Maintenance / refurbishment ● Condition / performance / risk	● Asset management plans ● Forward works program ● Valuation
Disposal	● Retirement ● Replacement	● Redeployment ● Demolition
Planning	● Asset related business needs ● Asset management strategy ● Asset options (asset/non-asset)	● Option economic analysis ● Investment metrics ● Plan agreed

Figure 24: Austroads Asset Management System (Austroads, 2018)

In addition, function groups (network, classification, and inventory) and asset management lifecycle phase covered in the standard are exemplified below.

- **Network**
  - **Planning**: Defining the sections of road that collectively describe the road network and its connectivity.
- **Classification**
  - **Planning**: Defining the road type by form or purpose.
  - **Operations**: Performing operations in respect to the defined road classification.
- **Inventory**
  - **Planning**: Providing an accurate record of the existing assets, which can be considered for recycling/reuse in a design phase for a refurbished/expanded asset.
  - **Design**: Identifying the assets and the related 'as-constructed' data requirements to ensure that this information is obtained and delivered.
  - **Construction**: Documenting the detailed 'as-constructed' assets and components including metadata where appropriate.
  - **Acquisition**: Capturing the scope of the assets in the asset register.
  - **Operations**: Accessing the inventory data for operational purposes.
  - **Disposal**: Removing the disposed asset from the asset register.

The Austroads Data Standard for Road Management provides comprehensive details on infrastructure asset management data requirement throughout the asset lifecycle mainly for road and associated civil assets.

4.3.4 Asset Classification System used by One Network Road Classification (ONRC)

The ONRC is the primary tool developed through the Road Efficiency Group (REG) to enable operational and culture change in road activity management. It facilitates a customer-focused, business case approach to budget bids for the National Land Transport Plan. Besides, it is a new framework that categorises all the roads. It will give road users more consistency and certainty about what standard and services to expect on the national road network, including the most appropriate safety features. It will also help New Zealand to plan, invest in, maintain and operate the road network in a more strategic, consistent and affordable way throughout the country.

The ONRC is a classification system, which divides New Zealand's roads into six followings categories based on how busy they are, whether they connect to important destinations, or are the only route available. Figure 25outlines these categories and their definitions.

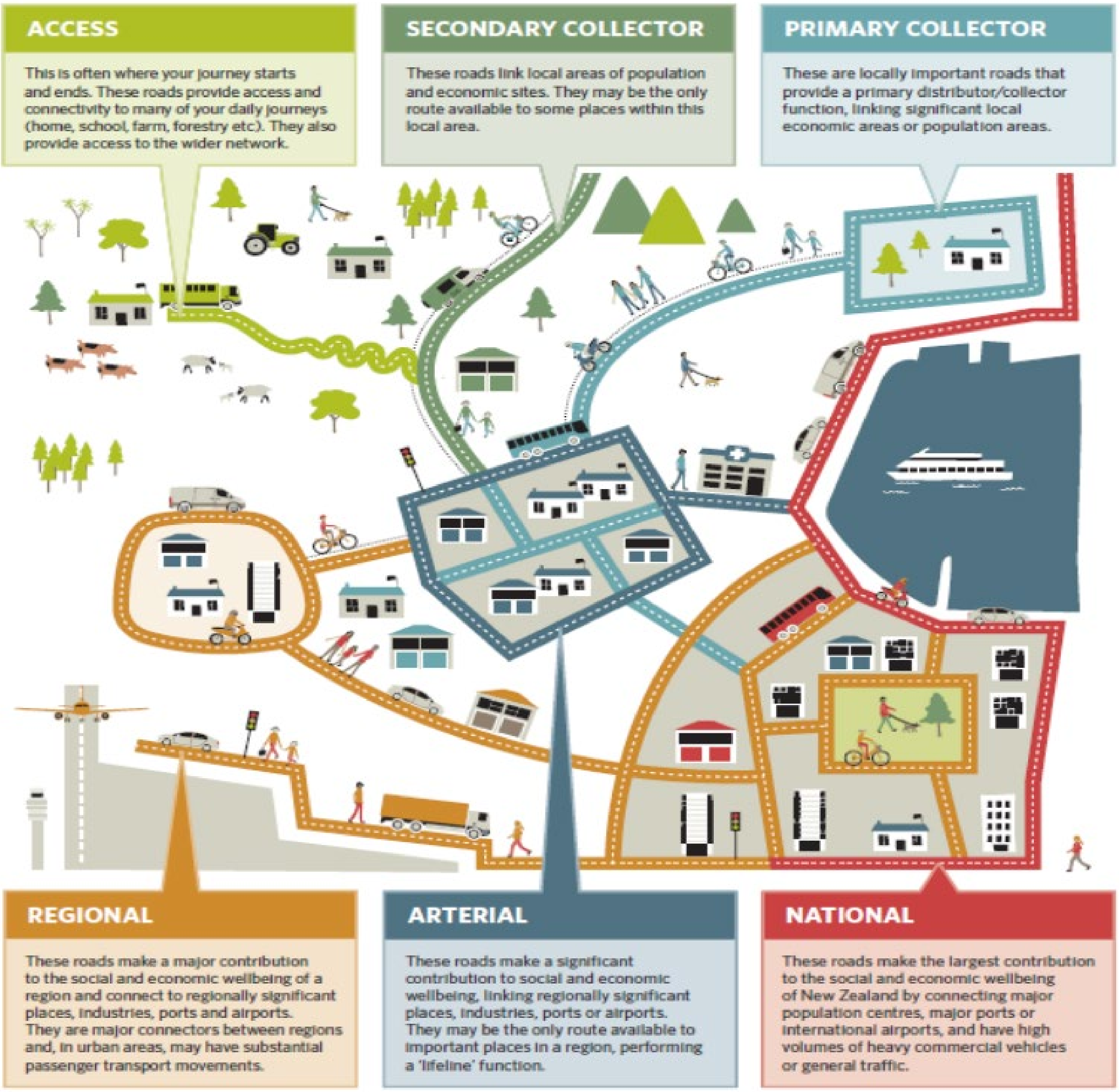

Figure 25: ONRC Classification

ONRC standard has three components: (1) Functional Classification. (2) Customer Levels of Service. (3) Performance Measures and Targets. Functional classification provides a detail definition for all type of road that can help to classify any road within six categories based on movement, economic and social activities. Figure 26 outlines the road classification description and Figure 27 provides examples of classified road network.

ROAD & STREET CATEGORIES/CRITERIA	FUNCTIONAL CRITERIA AND THRESHOLDS							
	MOVEMENT OF PEOPLE & GOODS				ECONOMIC AND SOCIAL			
	← LINK — PLACE →				← LINK —			
	TYPICAL DAILY TRAFFIC (AADT)[1]	HEAVY COMMERCIAL VECHICLES[2] (daily flows)	BUSES (urban peak)[3]	ACTIVE MODES[4]	LINKING PLACES	CONNECTIVITY	FREIGHT - INLAND PORTS/PORTS (per annum)	AIRPORT P NUMI (per an
NATIONAL Meet 3 criteria (incl. at least 1 of Typical Daily Traffic, HCV or Buses & 1 economic or social)	U[7]: > 25,000 R: > 15,000	>800	> 40 buses or 2000 people per hour		>100,000 population[8]		>2 million tonnes (or >$3 billion)[9]	>3 mil
(HIGH VOLUME) Meet at least 1 high volume (Typical Daily Traffic or HCV)	U: > 35,000 R: > 20,000	>1200						
REGIONAL Meet 2 criteria (incl. at least 1 of Typical Daily Traffic, HCV or Buses & 1 economic or social)	U: > 15,000 R: > 10,000	>400	> 40 buses or 2000 people per hour		>30,000 population[11]	Linking remote regions (regional councils) or sole connectivity in urban areas	>1 million tonnes[12]	>500,
ARTERIAL Meet 2 criteria (incl. at least 1 of Typical Daily Traffic, HCV or Buses)	U: > 5,000 R: > 3,000	>300	> 15 buses or 750 people per hour	Significant numbers of pedestrians and cyclists (urban peak) or part of identified cycling or walking network	>10,000 population[14]	Critical Connectivity (no alternative routes)		>250,
PRIMARY COLLECTOR Meet 1 criteria (incl. at least 1 of Typical Daily Traffic, HCV or Buses)	U: > 3,000 R: > 1,000	>150	> 6 buses or 300 people per hour		>2,000 population		< 1 million tonnes	<250,
SECONDARY COLLECTOR Meet 1 criteria (incl. at least 1 of Typical Daily Traffic or HCV)	U: > 1,000 R: > 200	>25			>250 population			
ACCESS All other roads	U: < 1,000 R: < 200	<25			<250 population			
(LOW VOLUME) Meet low volume Typical Daily Traffic	U: < 200 R: < 50							

Figure 26: ONRC Functional Classification

KEY	ROAD CATEGORY	ROAD NAME	CRITERIA ROAD MEETS
	National (high volume)	SH2 Tauranga to Te Puke (1)	3 criteria: Meets HCV volumes, linking places (Tauranga to Rotorua), access to Tauranga port for *National*. And above HCV threshold for *National High Volume* sub-category
	Regional	SH33 (2)	2 criteria: Meets HCV & Linking places (Tauranga to south – route continuity with SH2) criteria for *Regional*
	Arterial	Maketu Road (3)	2 criteria: Meets Typical Daily Traffic and HCV criteria for *Arterial*
	Primary Collector	Young Road (4)	1 criteria: Meets HCV criteria for *Primary Collector*
	Secondary Collector	Wilson Road North (5)	1 criteria: Meets Typical Daily Traffic and HCV criteria for *Secondary Collector*
	Access	Kaituna Road (6)	Meets Typical Daily Traffic criteria for *Access*
	Access (low volume)	Pah Road (7)	Meets Typical Daily Traffic criteria for *Access Low Volume*

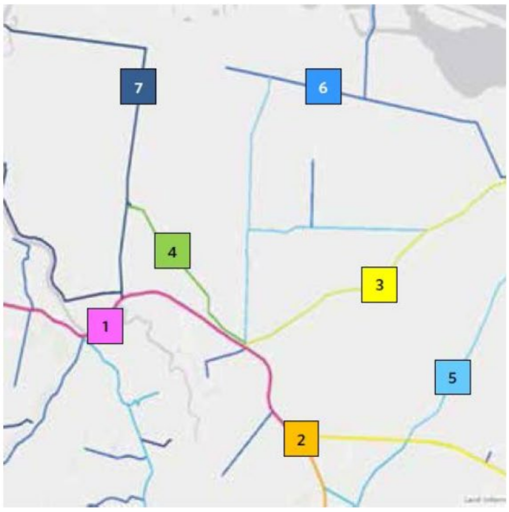

Figure 27: ONRC Functional Classification - Example

ONRC is not a complete classification system. However, as it only deals with a high-level functional classification of roads, it intends to support decision making for planning and investment and defines 'Levels of Service' for each classified road categories. In summary, this standard provides a high-level road classification category to support criticality assessment, asset management investment and maintenance prioritisation.

4.4 Summary

Classifications for Asset Information Management and Investment have been developed in response to a need to standardise and harmonise data sets that support common asset management and investment activities. Specifically, the Standard proposed in this project establishes a common understanding of the meaning or semantics of the data, to ensure correct and proper use and interpretation of the data by its stakeholders. The data specifications are specific to the data that is typically and routinely used for asset management and investment purposes. It provides consistency in data definition and format. This classification is designed to support asset information management systems for data collection, finance, risk, and information. It is the product of comprehensive consultation in Australia and New Zealand across the industry. The Standard allows organisations to determine their desired level of sophistication with respect to both asset inventory recording and asset management planning and provides the relevant data specification in this regard.

5 ASSET LOCATION REFERENCING

Location referencing for the interiors of housing and buildings is fundamentally different to that required on site, outside of buildings, and in infrastructure projects.

The Asset Location Referencing is a unique identification of a geographic object. A standard location referencing method allows for a common and unambiguous identification of object instances representing the same geographic phenomena in different geographic databases produced by different vendors, for varied applications and operating on multiple hardware/software platforms.

5.1 Asset Locations for Buildings

Assets within buildings are normally located within the spaces defined within the building. The IFC containment hierarchy (Figure 28) illustrates this. This information can be automatically extracted from a BIM model for new facilities. This data is normally gathered by hand for existing facilities where no BIM model exists. Simple tablet-based software supports this process.

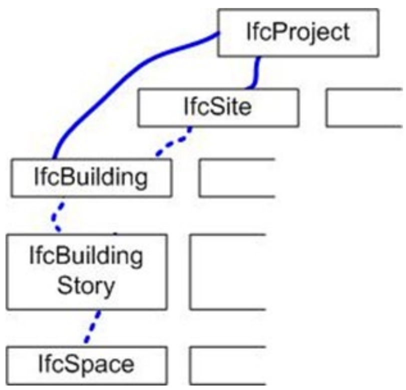

Figure 28: IFC Containment Hierarchy

Asset locations outside of the building envelope may be defined in:

a) Relative terms – the pathway leading to the front door;
b) Absolute terms – the north fence;
c) Absolute terms – as GPS coordinates; or
d) Using methods described below for infrastructure.

5.2 Overall Asset Location Referencing Model

The evolution of families of Location Referencing Methods (LRMs) is linked to the evolution of asset management in transportation infrastructure outlined in this section. Each jurisdiction in any country has developed different approaches over time. However, across jurisdictions, the various methods have similar properties and these may be categorised into three groups which are topological, geospatial, and geometric (Kenley and Harfield 2018).

5.2.1 Topological (Logical Linear and Network Referencing)

Topological LRMs describe locations along discrete but interconnected networks of features. An example from Sydney Rail is shown in Figure 29. This family includes traditional Linear LRMs, as well as the emerging and more comprehensive network-based models used by Intelligent Transport Systems (ITS) standards. The family is typified known points of connection, or interest (nodes), connected by line segments (links) and distance travelled. There are two groups of LRM within this family:

- **Linear referencing** (discrete linear elements)
  A group of methods within the topological family of location reference methods that specify a start position, a direction and a distance.
- **Network referencing** (topologically connected – routable – network of linear elements)
  A description of a complex arrangement of interconnected links and nodes that form an identifiable system.

Topological networks provide the same advantages as linear referencing for human cognitive models. However, they also provide a method for solving problems relating to routes or journeys. The obvious use is for journey guidance, such as navigation systems. Yet, for asset management, a more critical use is for service delivery management. The performance of a network for providing service to transportation users requires this level of analysis. Similarly, in order to preserve quality of service, it is desirable to understand the route for a journey and to be able to manage alternative paths in the event of disruptions such as roadworks and accidents. Indeed, it is critical for service performance that roadworks be planned with travel paths in mind and disruptions coordinated over significant service paths.

While it is technically possible to rely solely on a geographic information system (GIS) for the management of transportation infrastructures (as at least one smaller Australian jurisdiction does), such a solution loses much of the important functionality required for transportation asset and service management, and fails to protect the spatial relationships of objects.

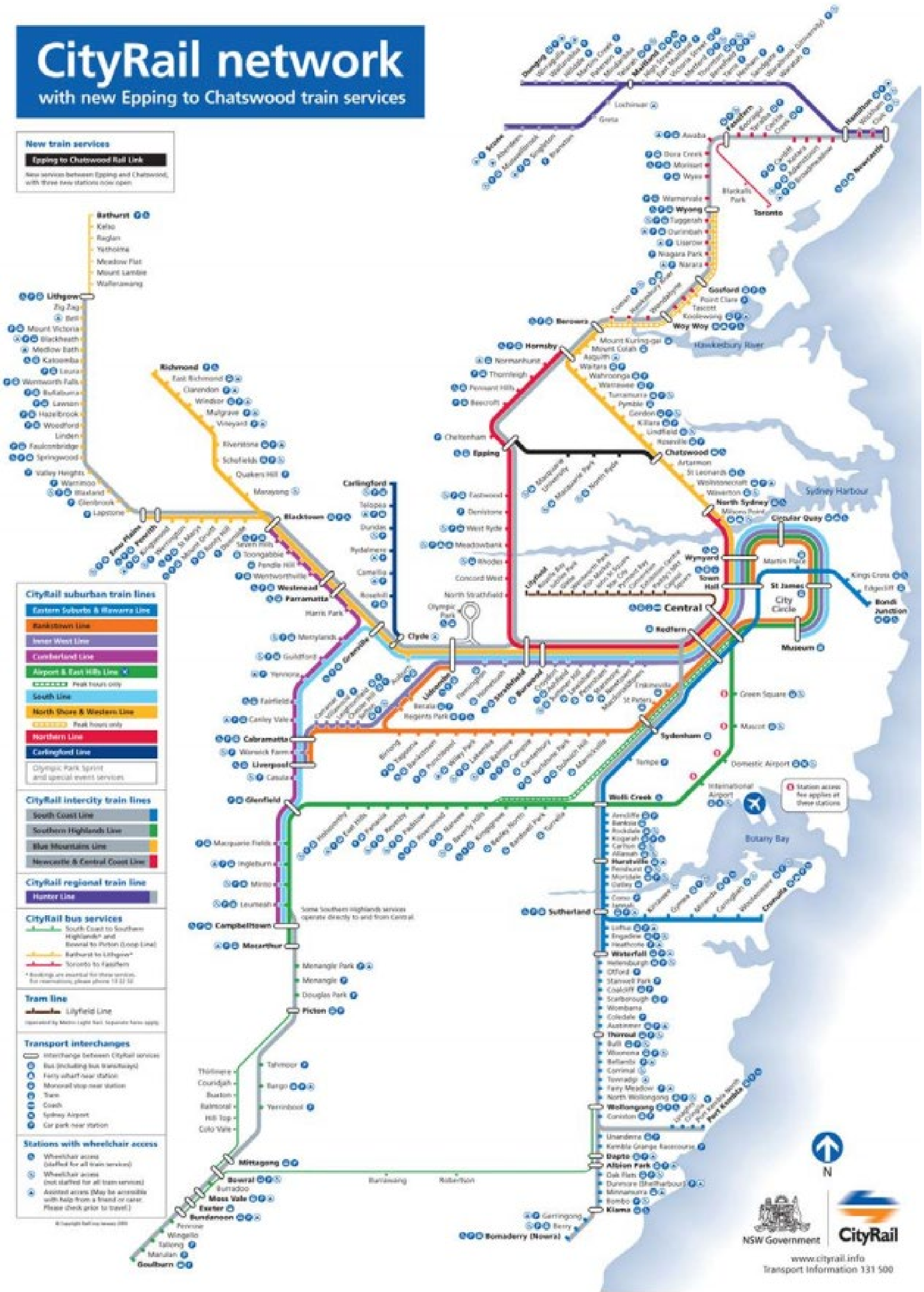

Figure 29: Sydney Rail - Topological Map (Source: CityRail, TfNSW)

5.2.2 Geospatial LRMs

Geospatial LRMs provide a way to describe locations on the earth's surface in real-world coordinates. This includes Geographic Information System (GIS) LRMs as well as coordinate-based mapping systems. The family is typified by line segments (links), known points of connection or interest (nodes), and real-world coordinates at nodes and also at regular intervals along links, or geographic polylines. GIS is a system to capture, store, manipulate, analyse, manage, and present all types of geographical data. Traditionally, GIS is based on 2D maps, in which objects are assigned 2D references such as longitude and latitude. Figure 30 provides an example of this type of relational map of road assets.

Searching and mapping are two key advantages to geospatial location reference systems. Most governments rely heavily on GIS applications for managing geographic data. These provide searching (proximity-based) and modelling abilities. Particularly, the GIS systems are able to call on much more than the asset database. Population data, terrain models, ground cover maps, etc. are all searchable. The typical application is therefore able to display a huge number of different features onto a map and this can be processed according to user needs. Thus, it is arguable that no modern transportation LRS could avoid having a Geospatial LRM as part of the system.

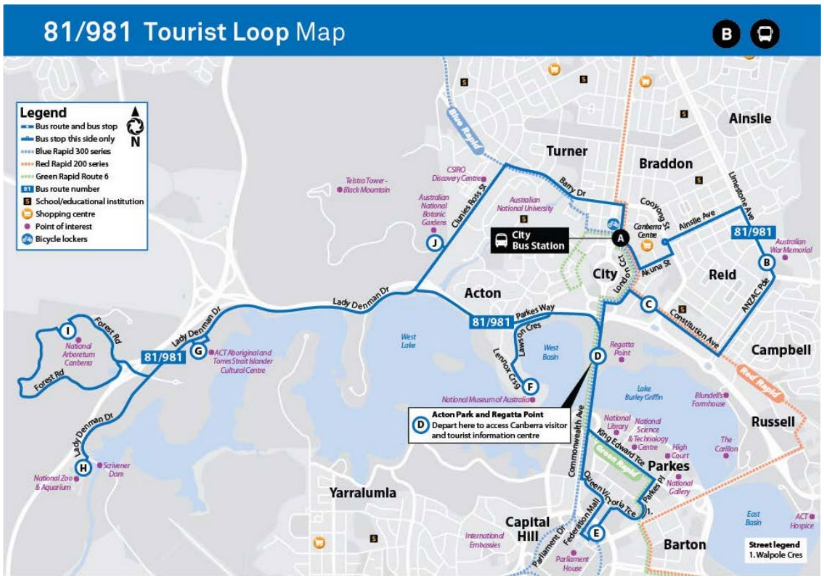

Figure 30: Canberra Tourist Map with 81/981 Bus Stops (Source: 81/981 Tourist Loop Map, Transport Canberra-ACT Government)

5.2.3 Geometric LRMs

Geometric LRMs are based on digital models that provide coordinate geometry within local model coordinates. Typically, these include digital design (2D or 3D) and BIM models. Some model environments are stand-alone and, more recently, they may be geo-connected (placed in the real world). The family of Geometric reference systems are those based on geometric models of infrastructure. They are typically created and used during design and construction. At the simplest level, geometric systems draft 2D representations of the design using relative coordinates (relative to a fixed and known point). Such systems use different methods to calculate the positioning of lines. Importantly, they are generally based on mathematical formula to form vectors. A line is from point A to point B and is straight or follows a mathematical curve. Thus, location references may be made in local coordinates and using mathematical vectors in 3D.

Geometric models of infrastructure include traditional 2D drafting of a project, through to 3D modelling, with the possibility of extending to include modern BIM workflows. These are the tools and methods of ‘BIM people’ as identified by de Laat (2011). Their world-view is based on technology, standards and syntax related to modelling. They make intense use of 3D geometry modelled through Industry Foundation Classes (IFC). These provide the rules for using the concepts of constructive solid geometry and boundary representation using Boolean operations to design geometric models of infrastructure (de Laat, 2011). However, it should be noted that the inclusion of older 2D and 3D modelling formats for infrastructure design means that Geometric LRMs is much more than BIM.

At the most advanced level, there are complex and powerful integrated systems to build models of infrastructure. This is the domain known as Digital Design in the horizontal infrastructure community and as BIM in the vertical infrastructure arena. Vertical and horizontal infrastructure have developed types of software systems suited to their specific contexts.

- **Vertical Infrastructure**: The term for built environment and infrastructure assets, that are suitable for object-oriented design. These typically are local and rise vertically, having the property of a location breakdown into discrete sub-divisions, such as floors, rooms, sections. Buildings and bridges are considered vertical infrastructure.
- **Horizontal Infrastructure**: The term for built environment and infrastructure assets, that are suitable for string-based design. These typically are linear elements with alignment as the principal feature, having the property of a location breakdown into continuous centre lines, such as road lines, chainage or networks. Road and rail lines are considered horizontal infrastructure.

Clearly geometric modelling using local coordinates is critical for the design and construction of infrastructure. As a coordinate system and with local coordinates for all objects and alignments, this forms a reference system.

5.3 Location Referencing for Building and Housing

Defining the location of assets for building and housing is a hierarchical process. Legally, buildings are located on a unique parcel of land and ownership of the building passes with the ownership of the parcel of land. Stories, whether they are full stories occupying the whole area of the building, or mezzanines covering part of the building area, are also easily distinguishable. Spaces or rooms within each storey are also normally clear cut. In some circumstances this is fine enough to provide a definitive location (Figure 31). In large open internal areas or shared workspaces then, individual workplaces will need to be numbered to provide a finer resolution.

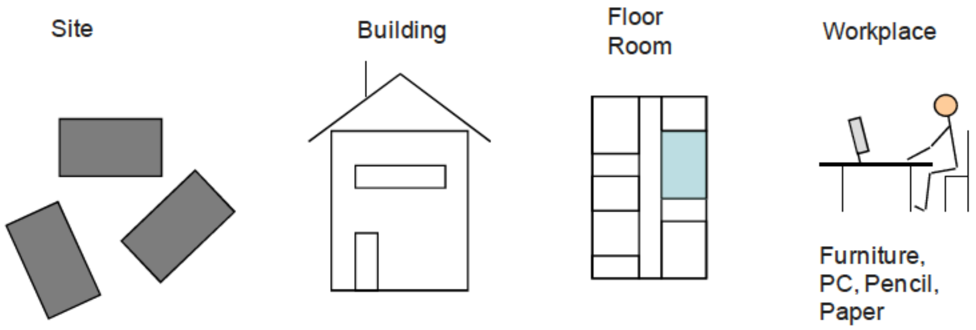

Figure 31: Assets at Various Scales (BS EN 15221-4-2011)

Unfortunately, with buildings, a straight spatial relationship is not adequate. The complexity of interrelated systems within buildings means that topological relationships must also be captured. For example, air conditioning register #2345 supplies air to space #56. Register #2345 is connected to fan #783 which draws its supply air from package unit #AV6. This supports tracing issues back to potential sources of problems. If space #56 is not comfortable, then air conditioning register #2345 can be checked for adequate airflow. Any problems can then be traced back through the system to assets #783 and #AV6.

Different hierarchical structures are illustrated in Figure 32 following.

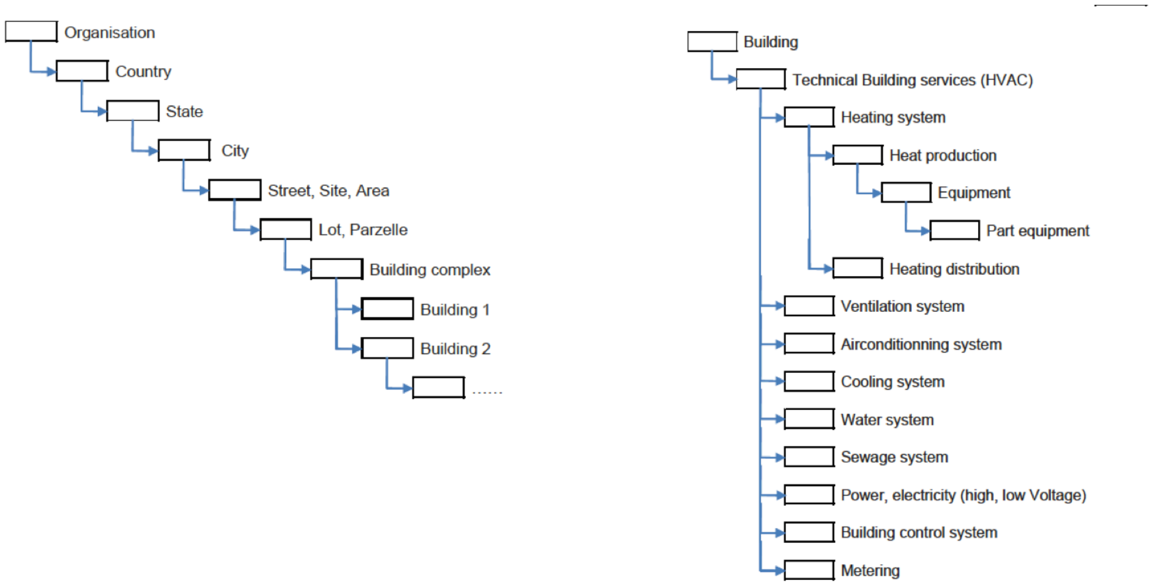

Figure 32: Different Hierarchical Asset Relationships for Buildings (BS EN 15221-4-2011)

5.4 Location Referencing for Transportation Infrastructure

Location referencing systems adopted by TfNSW, AS/NZS, and Austroads are reviewed to serve as examples for implementing location referencing for transportation infrastructure.

5.4.1 Location Referencing System used by TfNSW

The TfNSW transport network comprises infrastructure that covers both fixed infrastructure and mobile fleet assets including rotables. Fixed infrastructure assets shall be categorised as linear or non-linear whilst fleet assets shall be categorised as mobile. Fixed infrastructure assets are contained within four major asset containers, such as corridors, interchanges, facilities and feeders. These asset containers enable a structured approach to navigation within an asset register hierarchy. The asset containers as shown in Figure 33 are modelled together to form a concept model to define all road, rail and maritime networks.

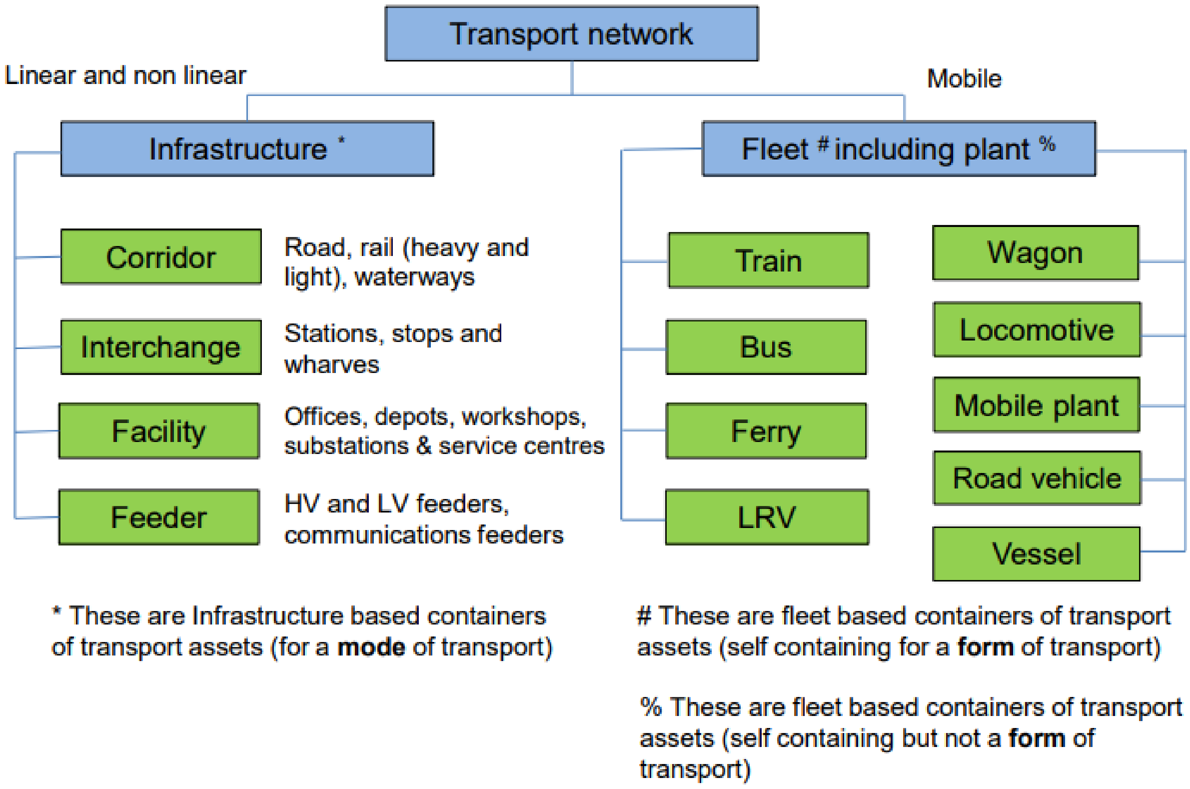

Figure 33: Asset Containers (Infrastructure and Fleet) (TfNSW, 2018)

Each infrastructure and fleet container shown in Figure 33 is defined as an asset container and shall contain systems and assets from other asset classes. Every instance of these asset containers shall be an asset in its own right. Figure 34 is an example of a typical heavy rail network concept model utilising infrastructure asset containers.

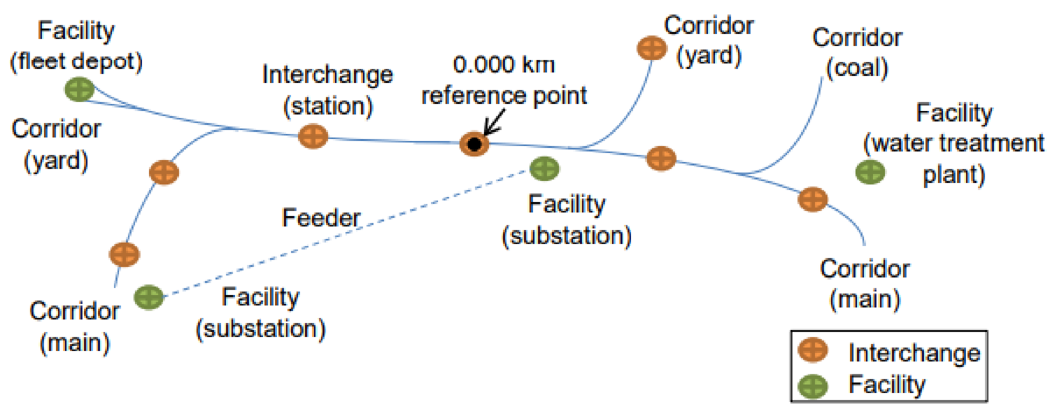

Figure 34: Example of Infrastructure Asset Container Concept Model (Heavy Rail Network) (TfNSW, 2018)

Rail corridors (main, coal and yard) are defined and bounded by the tracks they contain. Each individual track is defined as a base code. Figure 35 describes the corridor to base code relationship.

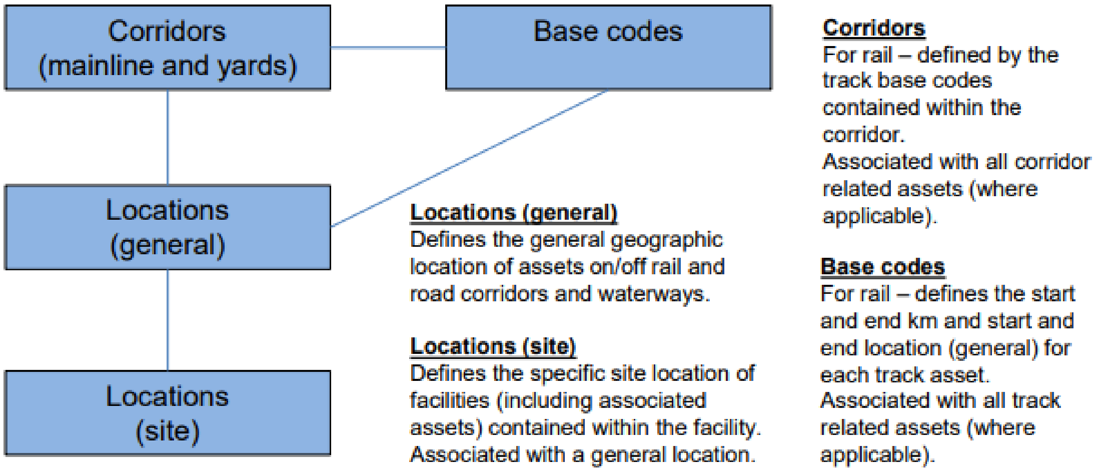

Figure 35: Entity Relationship with Corridors, Base Codes, General and Site Locations (TfNSW, 2018)

Figure 36 is an example of a typical maritime network concept model utilising infrastructure asset containers. Both infrastructure and fleet containers shall define and support a functional asset hierarchy of transport assets. Asset location classification (how and where the assets are located) is dependent on whether the container is infrastructure related or fleet related as shown in Figure 37.

Infrastructure and fleet asset containers shall be used to define a functional asset hierarchy of owned assets. Asset containers and the systems and assets within each container shall be defined. Every instance of an infrastructure container shall be associated with an asset container function and aligned with a primary and secondary location classification to determine the location of the container within the network. The tertiary location classification determines the location of the systems and assets within the container (position/space). Every instance of a fleet container shall be associated with an asset container function and aligned with a primary location classification to determine its home depot location.

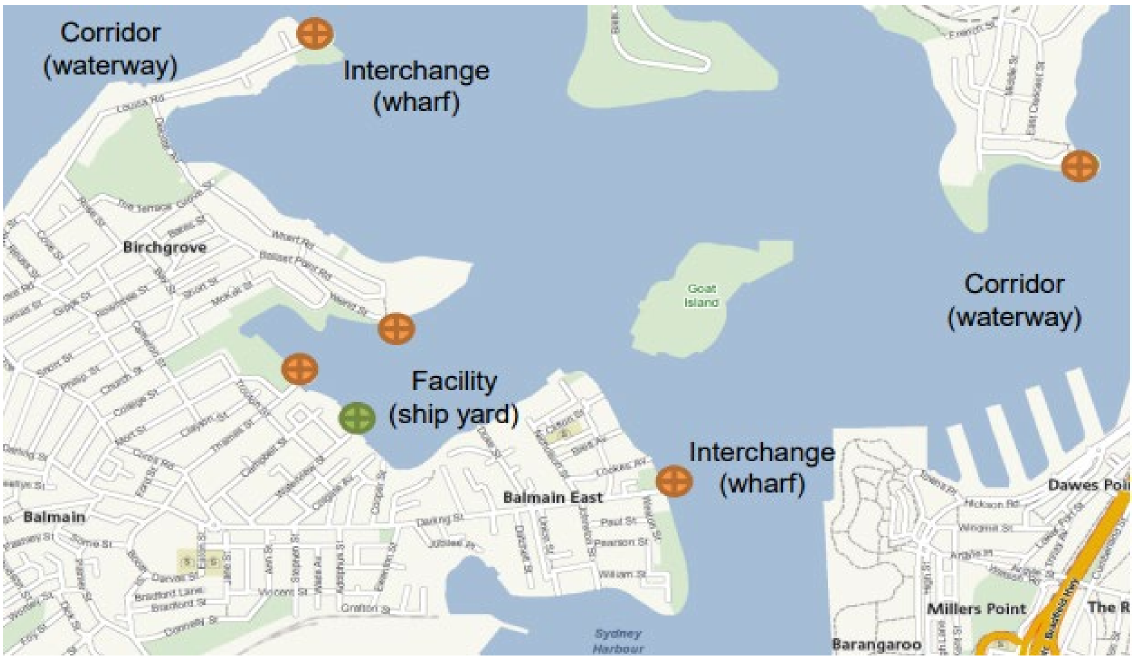

Figure 36: Infrastructure Asset Container Concept Model example (Maritime Network) (TfNSW, 2018)

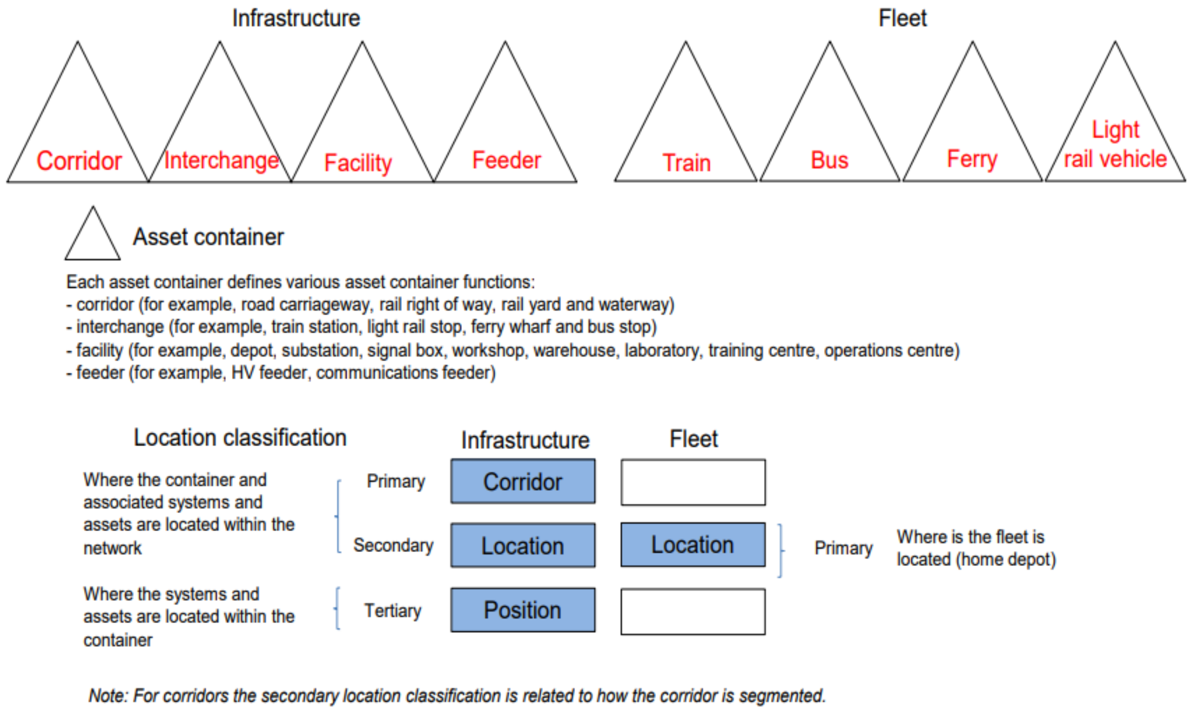

Figure 37: Asset Containers and Location Classification Concept Model (TfNSW, 2018)

Figure 38 indicates a typical asset functional asset hierarchy. The asset container defines all the functional systems, assets and sub-assets contained within an instance of the container. Asset location classification enables the physical location referencing of systems and assets within a functional asset hierarchy for every asset container across the transport network.

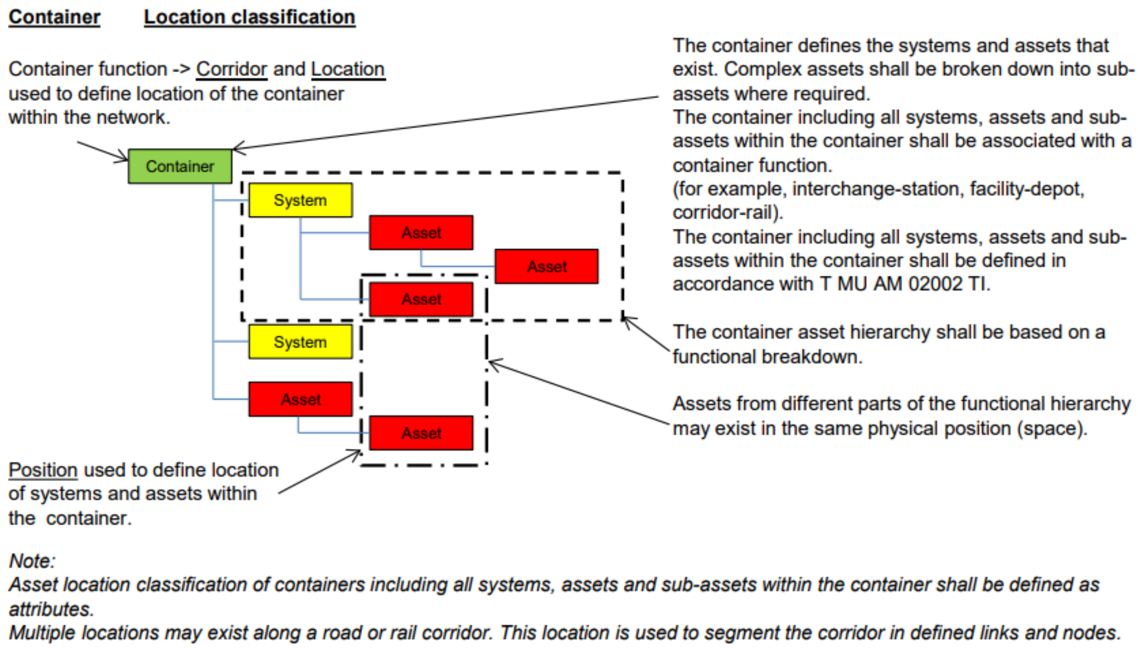

Figure 38: Asset Container Hierarchy Model (TfNSW, 2018)

Asset location classification supports the physical location referencing of these assets within the network and container.

The asset location classification shall be applied to identify both the general geographic and specific location (where applicable) of the following assets:

- Infrastructure assets (linear and non-linear) – These types of assets shall be defined, structured and managed in an asset register using an asset hierarchy as shown in Figure 38 and based on a corridor, interchange, facility or feeder asset container as shown in Figure 37.
- Fleet assets (mobile) – These types of assets shall be defined, structured and managed in an asset register using an asset hierarchy as shown in Figure 38 based on a fleet asset container as shown in Figure 37.

Asset location classifications defined in this standard as shown in Figure 37 cover the following:

- corridors
    - for referencing assets within a geographic rail corridor (heavy rail and light rail), road corridor or waterway
    - criteria for corridors including associated coding
- locations
    - general - for referencing assets within a smaller geographic area within a corridor (locality, interchange, rail yard, junction, colliery, quarry or waterway)
    - site specific - for referencing assets to a specific site (major facility) within a general location
    - criteria for locations and sites including associated coding
- positions
    - positions are dependent on the container. Corridors, interchanges, facilities and feeders will have varying spaces defined as positions within the container
    - track specific assets shall use base code to define position of track-based assets
    - overhead wiring specific assets shall use traction section to define position of overhead wiring assets
    - road specific assets shall use road link to define position of road-based assets

Other non-spatial asset location classifications including kilometre, level, room and address are not coded but shall be included as additional location reference attributes within the asset information system.

5.4.2 Location Referencing System used by AS/NZS

The standard used by AS/NZS specifies a conceptual schema for locations relative to a one-dimensional object as measurement along (and optionally offset from) that object. It defines a description of the data and operations required to use and support linear referencing. This standard is also applicable to transportation, utilities, location-based services and other applications which define locations relative to linear objects.

Linear Referencing Systems are in wide use in transportation but are also appropriate in other areas such as utilities. They allow for the specification of positions along linear elements by using measured distances along (and optionally offset from) the element. How a linear element is measured is specified by the Linear Referencing Method. The Linear Referencing Method specifies whether the measurement is absolute, relative, or interpolative. Absolute measurements, such as milepoint, hecto-metre and kilometre-point, are made from the start of the linear element. Relative measurements, such as a milepost, kilopost or reference post, are made from some known location along the linear element, called a referent. Interpolative measurements, such as percentage or normalized, use linear interpolation along the entire length of the linear element.

The Linear Referencing Method specifies if an additional offset measurement can be made perpendicular to the linear element to specify a location that does not lie directly on the linear element.

The offset measurement can be made from the linear element itself or relative from an offset referent, for example, 5 m from the reference line of a road or 5 ft. from the back of the curb, respectively. The Linear Referencing Method also specifies the units of measure for measuring along the linear element. This results in the fundamental difference between a milepoint versus a kilometre-point Linear Referencing Method; the first measures in miles, the second in kilometres. If a Linear Referencing Method allows offsets, the Linear Referencing Method also specifies the units of measure for offset measurements.

The measured value which defines the location along the linear element in accordance with the Linear Referencing Method is specified with a distance expression. In its simplest form, this is the "distance along" the linear element for an absolute Linear Referencing Method. It specifies how far along the linear element to measure from the start of the linear element in the direction towards the end of the linear element. The resultant "along" location A is on the linear element, as shown in Figure 39. For example, a distance expression with a "distance along" of 4.0 for a kilometre-point Linear Referencing Method along Route 1 specifies a location on Route 1 that is measured 4.0 kilometres along the route from its start.

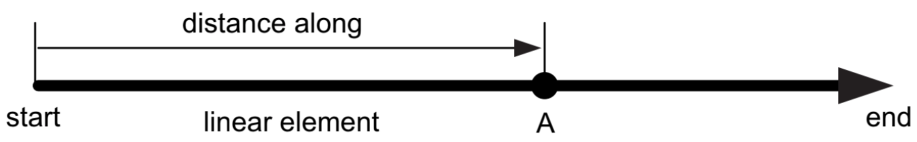

Figure 39: Linearly referenced along Location A with an Absolute Linear Referencing Method

For relative Linear Referencing Methods, the "distance along" is measured along the linear element from a known location on the linear element, called a "from referent", as shown in Figure 40. For example, a distance expression with a "distance along" of 0,5 for a kilometre-post Linear Referencing Method along Route 1 specifies an along location A on Route 1 that is 0,5 km along the route from the specified kilometre-post located at referent location R. If the kilometre-post is located 4.0 km from the start of Route 1, then the resultant location is 4.5 km from the start of the route.

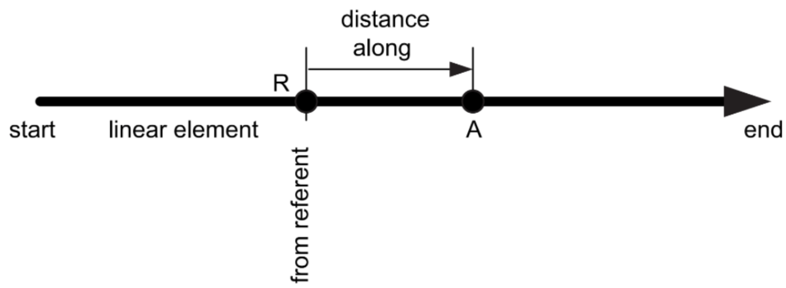

Figure 40: Linearly referenced along Location A with a Relative Linear Referencing Method

If the Linear Referencing Method is of type Linear Referencing Method with Offset, the distance expression may include an offset expression to specify locations not directly on the linear element. Each position expression may have either

1) a lateral offset
    a) measured left or right (perpendicular to) the linear element reference line from the distance along point,
    b) measured left or right (perpendicular to) a lateral offset referent,
    c) measured in a "lateral" direction defined by the LRS from the distance along point,
    d) specified by convention;
2) a vertical offset
    a) measured opposite to or in the direction of gravity, above or below the linear element from the distance along point,

    b) measured opposite to or in the direction of gravity above or below a vertical offset referent,
    c) measured in a “vertical” direction defined by the LRS from the distance along point;
3) a lateral offset and a vertical offset, measured as stated above;
4) a vector offset measured along a vector from the linear element; or
5) no offset at all.

Events could also be specified by using a Linear Referencing System. A linearly located event is an event that is located using a Linear Referencing System. It may reflect something which happens, like an automobile crash, or something that exists, like a roadway characteristic such as pavement type. Linearly located events are either feature events or attribute events. Feature events allow the location of a (located) feature along another (locating) feature. Attribute events allow the application of an attribute value to only a portion of a linear element, like the asphalt pavement type may apply only to the first half of Route 1, after which it changes to concrete.

Event locations are used to specify where a linearly located feature event occurs or where a linearly located attribute value applies. An event location can be either an “at” location or a “fromTo” location. If the event occurs at a single point along or offset from the locating feature, an “at” location is specified as the event location. The spatial extent is specified with a single linearly referenced location. If the event occurs throughout a contiguous spatial interval along or offset from the locating feature, a “fromTo” location is specified as the event location. The spatial extent is specified with two linearly referenced locations marking the start and end of the interval. “At” and “from/To” locations are depicted in Figure 41. The location labelled as LAT is the location “at” which the event occurs along the linear element. The locations labelled as LFROM and LTO are the “from” and “to” locations, respectively, along the linear element which bound the spatial interval throughout which the event occurs.

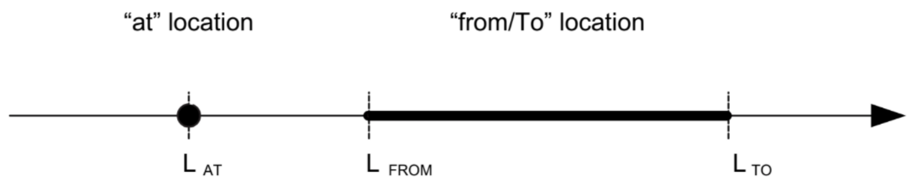

Figure 41: At and from/To event Locations

A single event instance occurs only in a single place. However, this single place may be described by both “at” and “from/To” locations. For example, a single city feature instance may have separate, scale-dependent “at” and “from/To” locations even though these two locations represent the same place.

Besides, it is also possible to specify the time at or during which an event is relevant. The instants and periods used to specify the temporal extent are valid times. Instant granularities vary and may be as short as defining a time precise to a fraction of a second or as long as an entire day or more. Figure 5.12 shows how event times can be combined with event locations. The location labelled as LAT is the event location, being the location “at” which an event occurs along the linear element. The locations labelled as LFROM and LTO are the “from” and “to” event locations, respectively, along the linear element which bound the spatial interval throughout which an event occurs. The time labelled as TAT is the event time, being the instant “at” which the event occurs along a timeline. The times labelled as TFROM and TTO are the “from” and “to” event times, respectively, along the timeline which bound the time interval during which the event occurs. Examples of events with location and time are:

- at instant event: crash;
- at period event (with offset): traffic sign;
- from/To instant event: street sweeping;
- from/To period event: pavement type.

Organisations may classify their events differently without deviating from this International Standard. The examples given are just possible choices among several possibilities. In a particular application schema, a particular crash can be modelled as a from/To period event to reflect a higher level of location precision. The key consideration is whether the location is specified at a single location or along a continuum delimited by two locations. This is analogous to a city feature having separate, scale-dependent point and polygon geometries (Figure 42).

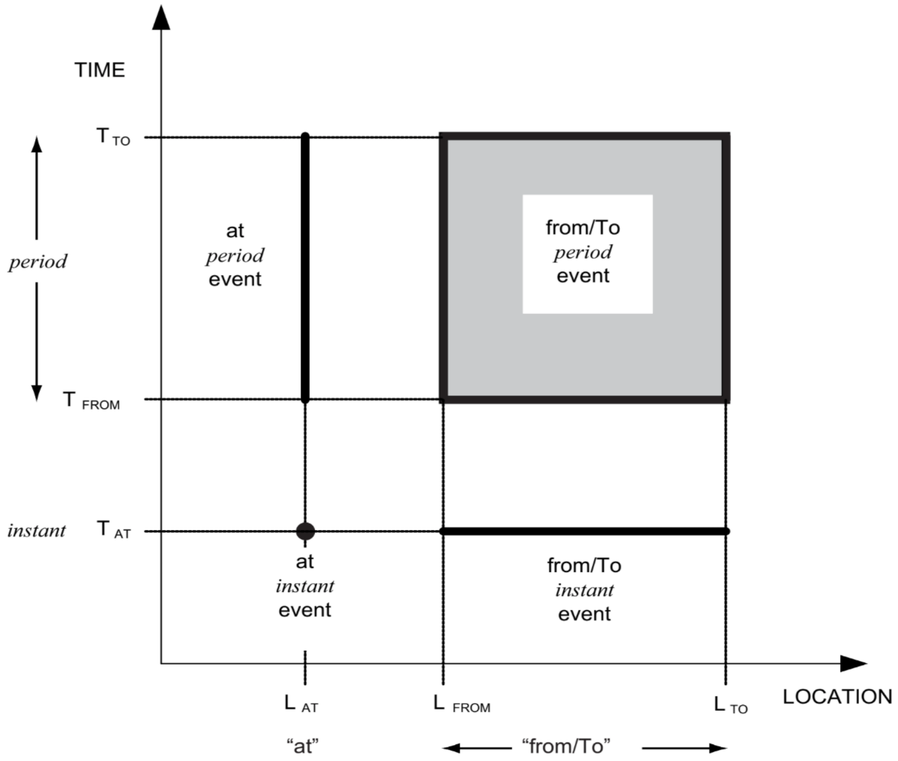

Figure 42: Events with Location and Time

5.4.3 Location Referencing System used by Austroads

Austroads investigate the potential to harmonise road location referencing and identify a feasible approach to harmonisation of road location referencing. It is discovered that when conducting a data collection survey on the network, it is important that the data is properly referenced and that location can be assigned repeatedly over time with a level of confidence. Without proper location referencing, users would have no way of discerning at what location the data was collected, severely limiting the use of the data. Generally, the location referencing methods adopted by Austroads member authorities can be separated into the two major categories:

- **Linear referencing** defines a location in terms of distance and direction in reference to another location (e.g. 15 km east of location X). Linear referencing is limited to a start and end reference point and is directly related to its geographical location.
- **Spatial referencing** defines a location using a set of coordinates, which describes a location in two or three dimensions, calculated using a mathematical model of the earth, where all locations are referenced to the same point or against a datum.

Many road authorities already maintain representations of their linear and spatial referenced road networks. Typically, their logical network is defined through linear referencing and variations between the two networks are reconciled whenever a change in either occurs. Some authorities already have their linear and spatial references integrated within a single system and this allows seamless transformation between the two reference methods. Any harmonised approach to road location referencing must be acceptable to

Austroads member authorities and this means it must enable an authority to retain their current location referencing systems. Consequently, any harmonisation approach must focus on universal road location referencing methods that integrate with an existing road referencing system.

Harmonisation of road location referencing can therefore only be achieved through supporting specific data collection applications and translation of location references into and out of ‘in house’ road location referencing systems as illustrated in Figure 43.

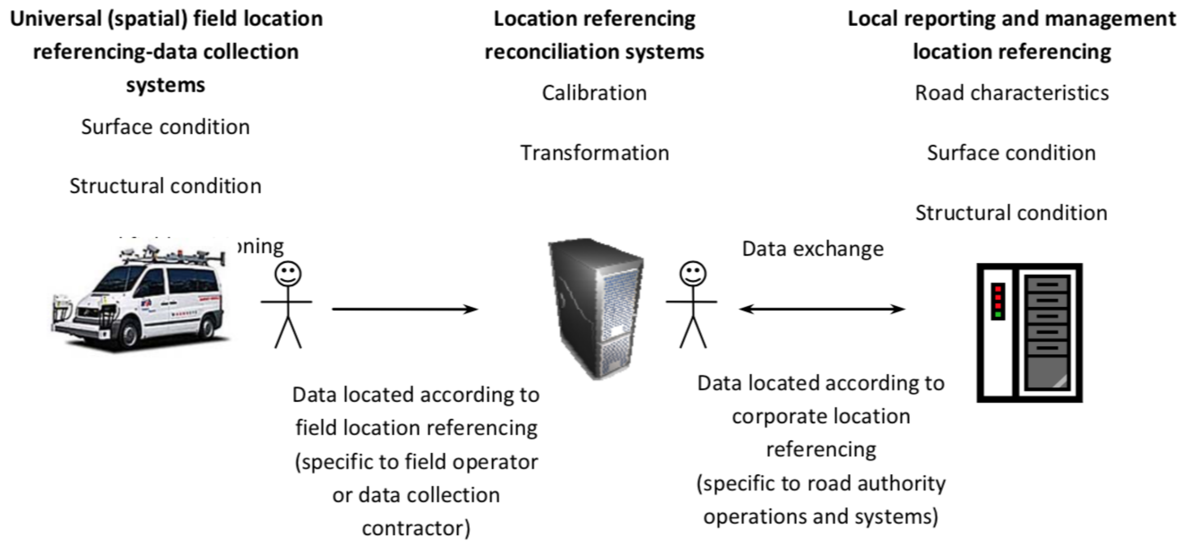

Figure 43: Illustration of a Harmonisation Approach to Road Location Referencing

The Austroads member authorities group agreed it would be an impossible task to develop and agree a common linear referencing system that can:

1. suit the needs of all member authorities
2. justify the expense involved in writing off the previous system and implementing a new system
3.

Hence, an alternative approach that allows road agencies to maintain their linear referencing legacy whilst enabling the utilisation of a universal approach to field positioning is needed.
Spatial referencing technologies and approaches offer such a solution. The following are the fundamental components required for the creation, acquisition, storage and application of a spatial referencing system:

- **Coordinate system** a reference system used to measure horizontal and vertical distances on a planimetric map.
- **Datum** mathematical model of the earth’s sphere which provides a frame of reference for measuring locations on the earth’s surface.
- **Projection** is a mathematical formula which enables areas on the surface of the earth (a spheroid) to be represented on a map (a flat surface).
- **Positioning** a means of determining the location/position of an object in reference to a datum.

In terms of coordinate system, features on the surfaces of the earth may be spatially referenced using either a geographic coordinate system or a projected coordinate system. Which coordinate system used is based on the application of the data, the datum and the projection method, namely:

- **Geographic coordinate systems** use latitude and longitude coordinates determined by a mathematical spherical model of the earth’s surface. Locations are described as latitude and longitude values which can be expressed in two ways: degree, minutes and seconds (DMS), expressed as 12°27’55.26 South 130°50’40.16 East; decimal degrees, in which latitude and longitude are expressed in decimal format converted from DMS. The example will be expressed as 12.465350° South and 130.844489° East in order to express a location to the nearest metre.

- **Projected coordinate systems** use a mathematical conversion to transform the latitude and longitude coordinates that fall on the earth’s three-dimensional surface onto a map which is a two-dimensional surface, on which the surface features can be represented accurately. Projection formulae take the geographic coordinates from the spherical earth (longitude and latitude) and convert them to Cartesian coordinates (X & Y). These coordinates may be expressed in a variety of ways, but the most common form is as ‘eastings’ and ‘northings’. The measurements of a projected coordinate system are done in imperial and metric units of measurement.

Next, a datum defines the spheroid used and the position of this spheroid relative to the centre of the earth, as well as the orientation of the latitude and longitude lines used in the coordinate system. The shape of the earth may be represented by a number of different spheroids / datum. There are two types of datum that can be used: local and geocentric datum.

- Local datum: A local datum aligns the surface of its spheroid to fit closely to the earth’s surface in a particular area. Therefore, the centre of the spheroid of a local datum is not at the centre of the earth.
- Geocentric datum: A geocentric datum uses the earth’s centre of mass as its origin. It is usually necessary to convert the coordinates to a local datum to make it compatible with other spatially referenced data, the datum currently used in Australia is the Geocentric Datum of Australia (GDA94). Due to movements of tectonic plates the fixed reference positions in Australia will change in reference to the WGS84, however, these fixed points will not change in reference to the GDA94.

Once data is collected using a datum (three-dimensional mathematical representation of the earth), projections are used to convert the data so that it can be displayed on a two-dimensional map. There are a variety of projections that can be used. Some common projections currently used by member authorities include: Azimuthal Stereographic, Lambert’s Conformal Conic, and Cylindrical Mercator.

Lastly, when the datum and projection has been defined, the location/position of an object can be obtained through the use of the Global Positioning System (GPS) and defined as an address in accordance with the coordinate system, datum and projection. A common application of spatial data is to establish the road centreline. This is a nominal line that shows the location of the centre of the road.

In considering the potential for harmonising road location referencing using a spatial referencing approach, a harmonised spatial location referencing method will require the following:

1. A standard geocentric datum such as WGS84 or GDA94, so that all vehicle-based data is referenced in the same format.
2. A location positioning approach, which can produce data in the form defined by the standard geocentric datum used. The collection technique may use GPS and inertial navigation systems, the accuracy of which will need to be superior to the current method of identifying and manually logging survey control points (particularly at traffic speed).
3. The use of the selected datum and preferred projection method to collect a stream of vehicle-based data that automatically contains sufficient and accurate spatial locations dispersed within the data stream to be able to confidently and accurately locate the survey. This varies from the old method of predetermining control points and then manually inserting them into the data stream by visual logging means during the survey process.

4. Overlay of existing linear referencing systems (which may differ between member authorities) on top of the surveyed data in order to transform linear references into the data stream. The prerequisite being that the member agency linear referencing system is integrated with a suitable and accurate spatial road centreline representation.
5. Use of this transformed linear data stream to determine section reporting intervals for calculation of desired attribute data, such as 100 m roughness values. This technique should minimise the extent and impact of rubber banding that is currently undertaken and provide more confidence in location repeatability. The transformed data format could remain consistent with the authority's current information systems requirements, enabling the whole process to be transparent.
6. The transformation process will need to report the location accuracy of the process so that member authorities can assess compliance with their location accuracy requirements.

A method that aims to demonstrate how linear location can be determined in the field without reconciling the complexities that may exist with the local linear referencing system. The method makes use of spatial positioning to calculate linear location in preference to determining linear location using manual interpretation and local knowledge. It assumes that the road authority has access to high quality spatial information across their road network and has accurately identified the location of selected node points (known as control points) spatially. The service provider will have a spatial measurement system of comparable accuracy in their survey vehicle to reported spatial location reference points for collected data.

Figure 44 provides supporting illustrations of the example used to describe the application of the proposed method. In the example, the road authority provides the service provider with the spatial data for the road to be surveyed along with the spatial position of at least two control points. Control points in this context refer to visible node points. Illustration B in Figure 44 is the spatial representation of this data which will include a combination of linear measures and spatial references. The service provider is required to report pavement condition data between the first and second control point using the clients linear referencing system.

Rather than manually entering visible reference points as part of the survey process (as typically occurs today), the control point is entered into the survey data stream based on the spatial information provided by the road authority (thus removing any human error resulting from the manual entry of the control point). This could be achieved in real time or during post processing. Illustration D in Figure 44 shows the spatial representation of this process.

The service provider is then required to report the pavement condition data at a fixed linear reporting interval (e.g. 100 m for roughness) from a defined location point on the road along with spatial identifiers for the start and end of each reporting interval resulting in a linear measure in a spatial environment (illustration E in Figure 44).

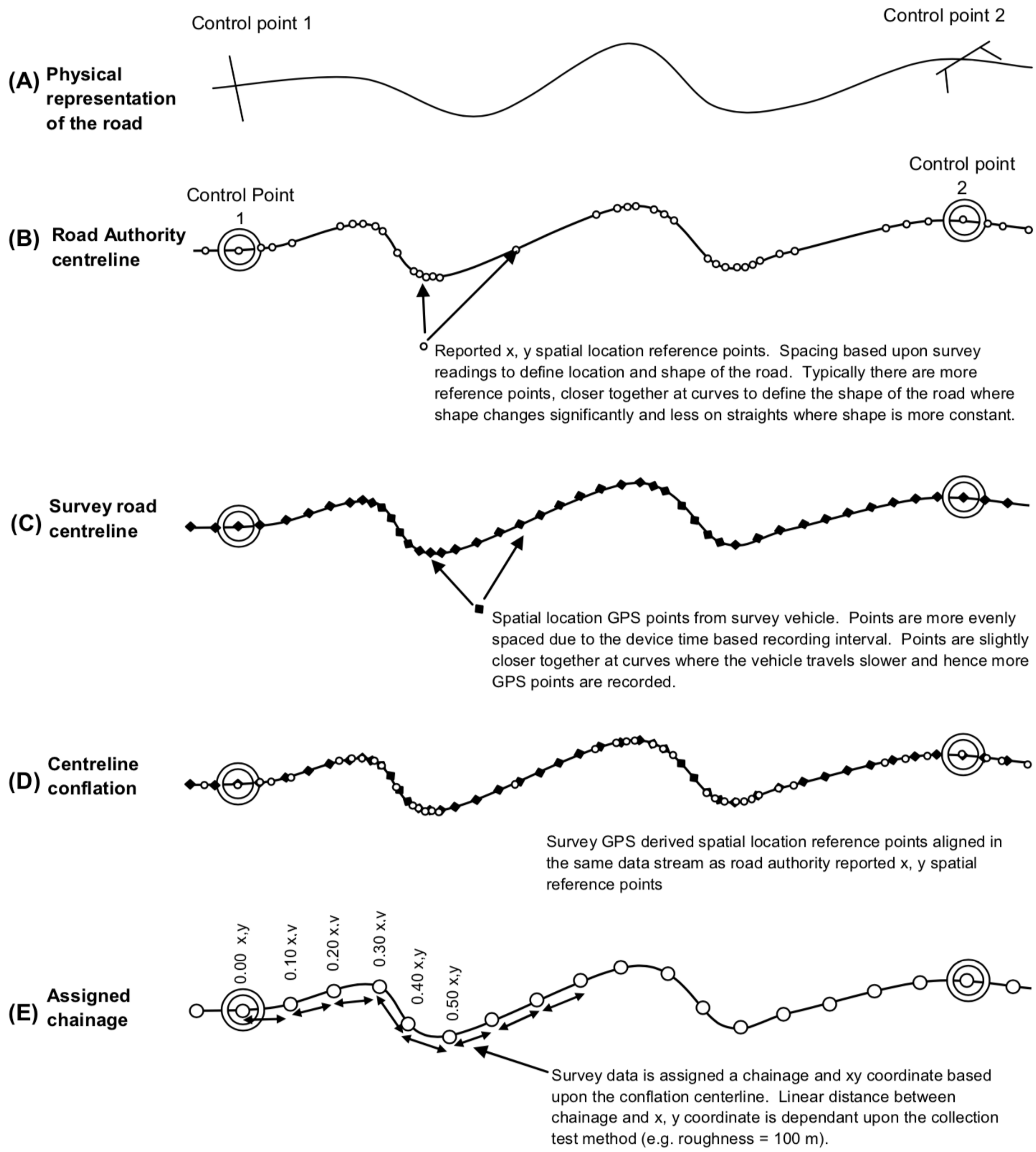

Figure 44: Potential Method illustration for applying Spatial Approach to Harmonise Location Referencing

Within the geospatial industry this approach would be referred to as a conflation process. Where conflation is defined as the process of combining geographic information from overlapping sources to retain accurate data, minimise redundancy and reconcile data conflicts. The goal of conflation is to combine the best quality elements of both datasets to create a composite dataset that is better than either of them. The consolidated dataset can then provide additional information that cannot be gathered from any single dataset. Because the sense of place plays such an important role in human lives, many kinds of non-geographical data can be tied to a place and thus become a candidate for conflation. This leads to the geographic reference becoming a primary key used by search engines and database applications to consolidate, filter and access vast amounts of relevant data from different data sources.

In this context the logical linear and spatial road centre line data become candidates for conflation because they have the potential to reduce the distance over which rubber banding type reconciliations are required.

The classes aforementioned (transportation feature, event, experience, spatial reference systems, and temporal reference systems) are essential and lay the foundation for the MDLRS data model.

The “transportation feature” is the central object of the MDLRS data model. The model is extended with a dynamic transportation feature called a “conveyance.” The transportation feature contains attributes that describe its spatial characteristics. These attributes can be quantitative (e.g., pavement index and vehicular volume), qualitative (e.g., colour of a sign), or temporal (e.g., operating conditions of an HOV lane and a signal-timing sequence). The attributes of a transportation feature can also have a validity period (e.g., January’s signal-timing sequence or the period when a volume was counted). Old values of a single attribute are stored in the transportation feature as a linked list, allowing for rollback of attributes. The administrative aspects of where the transportation feature came from and when it was instantiated are stored in the source metadata object.

An event, by its definition, produces changes in a transportation feature. Therefore, an event contains several methods that act on transportation features. An event can add or modify attributes of a transportation feature (e.g., updated traffic volume), can add or modify a spatiotemporal object of a transportation feature, can add or modify attributes of a spatiotemporal object (e.g., widening of a roadway), and can retire or instantiate transportation features (e.g., installation of guard rail). In the case of a conveyance, events can initiate and stop the movement of the conveyance (e.g., the use of daily public transport vehicle assignments or “blocking”). Collections of related events are called complex events and allow for modelling of multiple activities (e.g., a construction schedule for a certain year, the logistics of the Olympic Games, the parade schedule for a major city, or the transit schedule for a weekday).

The experience object is an event object, the experience object does not contain any data. The experience object contains references to the activating event, as well as references to the new or modified transportation feature. Users can perform historical queries because the experience object contains references between event and transportation feature objects. To perform the historical queries, users trace an event to the affected objects of a feature. Having the experience object contain references also works in reverse (i.e., tracing the affected objects of a feature to an event through an experience). Rollback of an entire transportation system is possible through the experience objects of its transportation features.

The MDLRS data model has five categories of SRSs: vertical, geocentric, horizontal, cadastral, and linear. Each SRS has one or more datum objects and an associated reference object. Reference objects are transportation features, can lie on other features, and are spatially represented as reference points. Table 5 presents the datum objects and reference objects for each of the five SRSs.

Table 5: Characteristics of Spatial Referencing Systems

Name	Dimension	Datum Object	Reference Object
Geocentric	3D	3D Cartesian Axes	GPS Satellite
Horizontal	2D	Ellipsoid	Control Station
Cadastral	2D	Corner	Corner Point
Vertical	1D	Geoid/Local Datum	Benchmark
Linear	1D	Anchor Point/ Anchor Section	Traversal Reference Point

As shown in Figure 45, a TRS consists of a temporal datum and temporal referencing methods containing temporal reference equations. The MDLRS data model uses a temporal datum object and one or more temporal referencing method objects to represent the TRS. In the MDLRS data model, the temporal referencing method object contains a temporal reference equation method, which is a derivable equation that relates the temporal datum to the temporal referencing method. The equation consists of two parts: a reference offset (e.g., −3 h for zonal time), and a metric scaling function that relates the metric of the method to the metric of the datum (e.g., to convert between Julian dates and Gregorian calendar time). Although the MDLRS data model can accommodate various metrics and various temporal representations, the data model concentrates on temporal referencing methods whose metrics are the same as the datum and assumes UTC and the Gregorian calendar as the temporal datum.

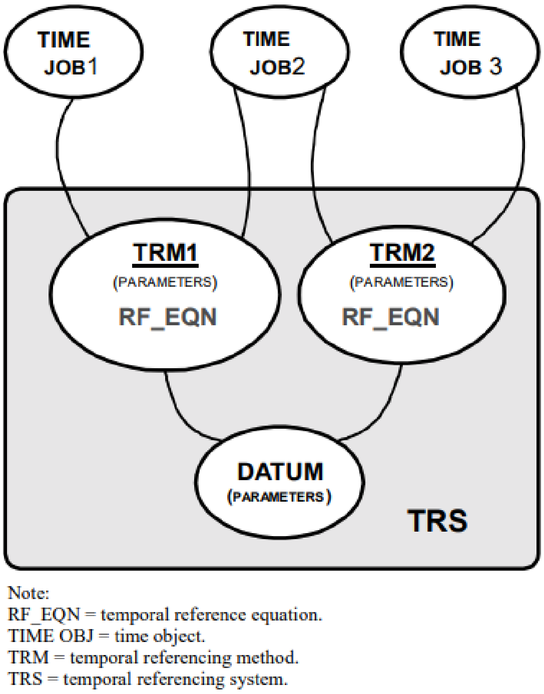

Figure 45: Schematic of a Generic Temporal Referencing System

5.5 Summary

The specification of the location of assets within buildings is fairly consistent with the location hierarchy defined within the IFC model being supported across the major vendors of building design software. This means that the importation of building asset information into an asset database can be relatively straight forward if the source data is well structured, consistent and accurate.

Currently, most transportation authorities use linear referencing methods as their primary means of referencing locations within their network. These methods are simple to understand; however, they incur high installation and maintenance costs in order for them to be an effective referencing tool and they are a relative referencing tool because the physical markers used as reference points may change over time as the network is altered.

A move to spatial referencing as the main method of location referencing asset data is anticipated. Given the current issues and constraints associated with spatial location referencing, a new spatial approach to location referencing is likely to require some years to develop and to integrate as each member authority develops and acquires an accurate spatial representation of its centrelines. Over time this technology will become common among all member authorities, and new spatial referencing methods and systems may be adopted as a standard for field location referencing.

6 ASSET INFORMATION REQUIREMENT

To enable the owner to safely and effectively operate new assets and refurbished assets, asset information requirements need to be stated clearly before construction commences, and needs to define the responsibility of transferring the data between organisations.

Asset information is composed of Data (Graphical data, Non-graphical data) and Documents (Figure 46) (TfNSW, 2019b).

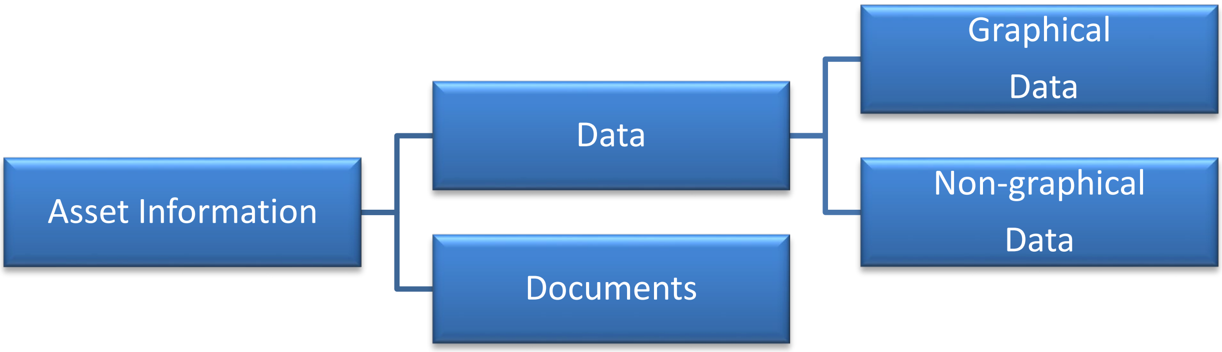

Figure 46: Asset Information Component

With reference to Graphical Data, it describes an asset's graphical attributes involving actual attributes in terms of size, location, position and spatial attributes. On the other hand, non-graphical data consists of configuration, condition, operational, maintenance, organisational and financial attributes. Asset information data could be defined into the following data groups:

- Location
  Location data contains physical and geospatial attributes
- Configuration
  Physical and functional data identify and provide static reference of manufacturer details, asset construction, asset procurement, technical characteristics
- Condition
  Past and current condition data, such as information on residual life
- Operational
  Operational data related to usage, tonnage, restrictions and criticality
- Maintenance
  Data stipulate management and recording of maintenance activities
- Organisational
  Organisational data illustrate the framework referring to responsibilities of the owner, operator and maintainer
- Financial

Financial data record costing of the whole project life cycle from capital acquisition, operation, maintenance to disposal

Besides the above-mentioned data, asset documents, composed of manuals, plans, photos, drawing, models, certificates, licences and schematics, store and satisfy requirements of asset handover. Considering convenience of asset information handover, all CAD drawings and models are requested to define and submit with standard form of handover requirements.

Asset information is generated across the asset lifecycle. Figure 47 demonstrates the four stages in asset life cycle.

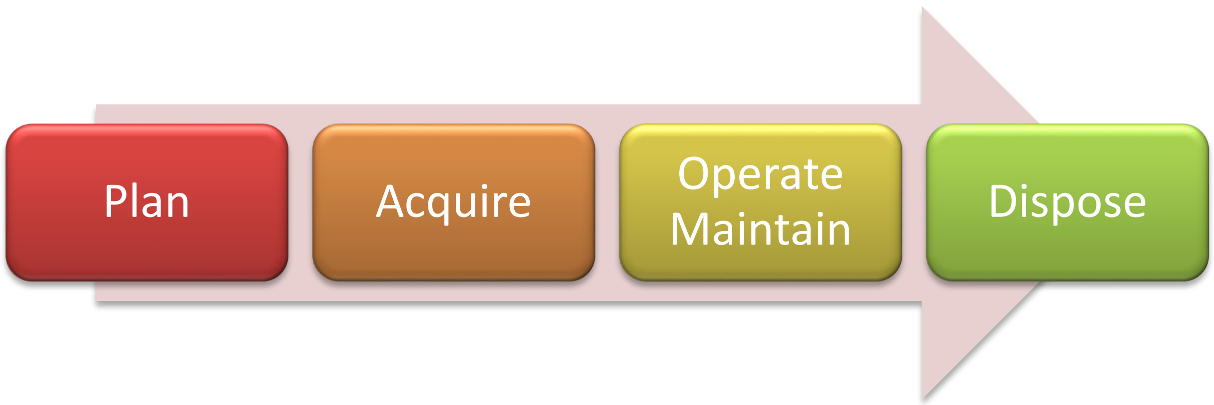

Figure 47: Asset Life Cycle Stages

During this asset lifecycle, asset information shall be assessed unceasingly to ensure data and documents quality, supporting and substantiate asset information to meet asset information requirements. The asset information quality shall be determined by the following categories:

- Completeness
- Correctness
- Consistency
- Clarity
- Integrity
- Uniqueness

Prior asset handover and asset acceptance phase, asset information requirements shall be collected and managed at the stage of plan and acquire. Providing and updating the following detailed asset information requirements facilitates asset handover, commissioning, operation and maintenance.

1) Plan stage

   a) Documents

      At the commencement phase, asset information linked to requirements specification, feasibility, environmental, geotechnical reliability, availability, maintainability and safety (RAMS), system safety assurance plan and hazard log, shall be recorded and submitted.

2) Acquire stage

   a) Configuration Data

      i) asset register identifier

      ii) construction or build

      iii) asset status

      iv) date commissioned and design life

      v) design information

      vi) supplier or vendor data

      vii) failure modes, effect and criticality (FMECA)

      viii) test and commissioning results

      ix) warranty data

      x) survey data

      xi) heritage data

xii) spare parts inventory

b) Location Data

   i) physical geographic and geospatial referencing data

   ii) environmental data

c) Organisational Data

   i) asset ownership

   ii) asset maintainer

   iii) asset operator

   iv) third party agreements

   v) land ownership, deeds and agreements

d) Operational Data

   i) asset criticality and assessment criteria (design)

   ii) operational settings such as circuit breaker trip setting

   iii) hazards – confined space and restrictions

   iv) risk level

   v) energy usage

   vi) special requirements to operate and maintain

e) Financial Data

   i) capital acquisition cost

   ii) operate and maintain cost

f) Documents

   i) maintenance standards and technical maintenance plans (TMPs)

   ii) maintenance manuals

   iii) operating manuals

   iv) drawings – includes concept, approved for construction and as-built drawings, schematics, plans and cad files, and models

   v) regulatory – includes licensing and special conditions

   vi) certificates and compliance

   vii) reports – includes design assumptions and calculations, inspection and test reports, commissioning reports and safety assurance reports

Above mentioned asset information requirements are required for new assets as well as renewal or refurbishment of existing assets. In addition, asset information shall be continually assembled throughout whole life cycle including operation, maintenance and disposal phases as shown below in Figure 48.

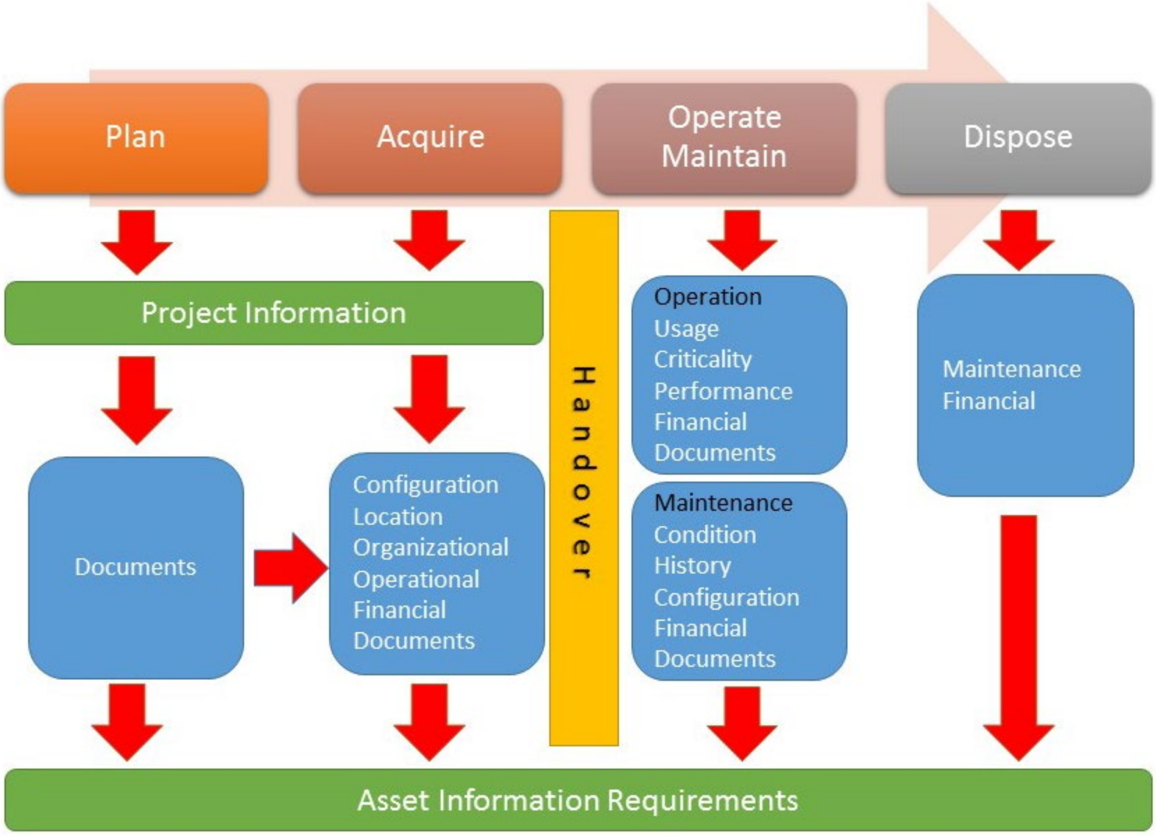

Figure 48: Asset Information Requirements Lifecycle (TfNSW, 2019b)

At the stage of operation and maintenance, the following asset information requirements shall be acquired and managed:

1) Configuration Data
    a) asset status
2) Condition Data
    a) asset condition and assessment criteria
    b) remaining life
3) Operational Data
    a) asset criticality and assessment criteria
    b) asset utilisation and capacity – includes performance requirements
4) Maintenance Data
    a) maintenance activities data
        i) preventive service schedules
        ii) work orders for maintenance activity
        iii) defects
        iv) work breakdown structures
        v) unit rate estimates
        vi) duration
        vii) maintenance activity records – includes measurements, adjustments and calibration records

viii) material used

b) failure or incident management data

i) time – includes time failed, time attended, time rectified and time in service

ii) defect and asset related to failure or incident

5) Financial Data

a) Maintenance cost – includes labour, material, plants and equipment and contract

b) Capital value

6) Documents

a) photos

b) reports

c) concessions provided to maintenance standards

In regard of disposal stage, asset specific decommissioning information shall be captured and managed as shown follow:

1) Maintenance data

a) Maintenance disposal activities

b) Work orders for maintenance activity

2) Financial data

a) Disposal costs – includes labour, material, plants and equipment and contract

b) Residual capital value

6.1 Asset Information Requirement for Housing and Buildings

The asset requirements for housing and buildings will depend on the facility owners/managers requirements. APPENDIX B - Minimum Attributes for COBie Data covers the minimum requirements defined by the US government's General Services Administration, the largest building owner in the world.

The grouping of assets will depend on the asset manager's requirements and the configuration of the assets. For example, individual luminaires (light fittings) may be defined within offices, but in general work areas where there may be hundreds of luminaires operated from several switches, then the luminaries would be defined as a group and storing the number thereof.

6.2 Asset Information Requirement for Transportation Infrastructure

6.2.1 Road Asset Information Requirement

Considering pavement or road asset information requirement for handover phase, specific asset information shall be captured and managed for the next operation and maintenance phases.

6.2.1.1 Inventory Data

In order to check the compliance of the description and definition of the physical properties of the road, stored in the asset register. In this asset register, all assets and sub-assets shall be listed by following items:

- Name
  - defines the unique name of the whole road
- Unique Identifier
  - links to one single road or part of road

- Location
  - locates the road, the most fundamental and critical attribute linked to all road related data to each other
- Jurisdiction
  - describes legal status of the road including owner, managing agency and governmental jurisdiction
- Geometry
  - includes size and other geometric characteristics defining the road
- Constituents
  - states the composition and materials of the pavement in groups,
    - pavement type
    - surface type
    - base type
    - sub-base type
    - subgrade
    - layer thickness for the above
- Classification
  - defines road significance and maintenance priorities based on the road function

6.2.1.2 Condition Data

In the phases of operation and maintenance, collecting road condition data is the most important regular operation. The road condition data reflects current physical properties; therefore, the recorded data shall be associated with the date. To critical road, condition data collection interval should be shortened ensuring that updated condition data could reflect accurate road condition.

Condition data is composed by following three major parts:

- the name of the distress or parameter
- the severity or magnitude of the distress
- the extent of the distress

6.2.1.3 Environmental Data

Due to roads operate exposed to the environment, the road performance is impacted by environmental condition heavily. Major environmental condition shall be captured by following items:

- Geographical data
  - topography (hilly, mountainous, flat)
- Climate data
  - temperature regime
  - rainfall
- Construction data

6.2.1.4 Road Use Data

Road use data is linked to road deterioration and long-term performance. Effective road use data collection and update could extent road usage life. The road use data includes following items:

- Traffic volume
- Axle load
- Traffic growth

6.2.1.5 Construction, Maintenance and Expenditure Data

Road condition is kind of dynamic result linked to construction and maintenance condition. To collect the latest reliable road composition or condition, the understanding of the history of both construction and maintenance is playing a vital role.

6.2.2 Bridge Asset Information Requirement

With regard to bridge asset information requirement, various data related to bridge asset management shall be captured and managed:

6.2.2.1 Inventory Data

Bridge inventory data describes identified and administered information of bridge management:

- bridge identification, location and function descriptors
- structural information, with descriptions of foundations, substructure, and superstructure
- structure live load capacity
- attachments, e.g. services/lighting
- environmental and historical listing
- geometric details, including alignment and clearances

6.2.2.2 Inspection Records

Regular inspections could reflect bridge current condition. Supporting management practices ensure the safety of bridge usage. Inspection records shall be divided by different type of bridge:

All bridges

- visual observations and soundings

Concrete and steel bridges

- destructive and non-destructive testing, crack detection, corrosion detection, stress detection

Timber bridges

- probing, boring, moisture measurement

Special inspection

- radar, thermography, underwater inspections, precision levelling, photogrammetry, acoustic monitoring, chloride testing, crack movements measurement

6.2.2.3 Bridge Design and Construction Data

At bridge asset information handover phase, detailed and precise design and construction data make much contribution to bridge asset management in both operation and maintenance phases.

In regard to bridge design information, the following asset information should include:

- drawings, including bridge dimensional and location information
- bore logs, including structural foundation information
- hydrological information, including hydrological data for bridge design
- design load capacity
- bridge safety barrier performance level
- refurbishment design information including widened and strengthened information

On the other hand, construction information supports bridge operation and maintenance management as well, including the following item:

- construction date and cost
- special data
- pile working record
- concrete placing record
- prestressing and post-tensioning record
- coating work record
- photographs and video record

6.2.2.4 *Stream Flow*

Stream flow information is vital information for the bridge over waterways, including flow characteristics of the stream. This information plays key role in preparing for flood events, avoiding damage and disruption caused by flood.

Stream flow information consists of the following data:

- flooding record, including level, date, period and amount.
- debris record
- scour record

6.2.2.5 *Traffic Surveys*

Based on traffic surveys information of bridge in terms of vehicle numbers, types and mass, the traffic trend and prediction could be simulated and analysed, which is a significant part of bridge asset management. The traffic surveys comprise below data:

- traffic volume, including the volumes of vehicular, pedestrian and cycle traffic
- traffic spectrum
- heavy load

6.2.3 Tunnel Asset Information Requirement

Tunnel structure is transportation corridor to link roadway and railroad as well as various utilities. Compared with other transportation infrastructure, safety issue takes large amount of time and cost in tunnel projects, which could be promoted by applying asset management system. The tunnel asset information requirement of project handover illustrates the following aspects:

6.2.3.1 *Inventory Data*

The inventory data of tunnel asset information shall be derived by the following items:

- tunnel identification, location, types and function descriptors
- structural information
- structure live load capacity
- mechanical information, including ventilation systems
- electrical information, including lighting systems
- attachments, including track, power, signal and communication systems
- environmental and historical listing
- geometric details, including alignment and clearances

6.2.3.2 *Tunnel Design and Construction Data*

The below tunnel design data shall be submitted for tunnel operation and maintenance:

- approved drawings, including as-built drawings and any modified construction drawings
- cad files and models represent part or whole of approved design
- tunnel type information
  - shapes, includes highway tunnels and rail transit tunnels
  - liner types, includes unlined rock, rock reinforcement systems, shotcrete, ribbed systems, poured concrete and slurry wall
- tunnel geometric detail
  includes tunnel width, horizontal clearance, tunnel height, vertical clearance and safety walk width
- ventilation system information
  - types, includes natural ventilation, longitudinal ventilation, semi-transverse ventilation, full-transverse ventilation and single-point extraction
  - equipment, includes fans and other supplemental equipment
- lighting system information
- tracks information
- power system information

- signal and communication system information
- risk management, includes escape plan
- design load capacity

During the tunnel construction, construction data and condition of all above mentioned aspects should be recorded detailed by photograph and video with the date and cost.

6.2.3.3 Inspection Records

In operation and maintenance of tunnels, inspection records represent fundamental element impacting all-around systems, regardless of inspection recorded in construction or operation/maintenance phases. In the tunnel project, inspection records could be specified by the following fields:

- structural systems
- mechanical systems
- electrical systems
- other systems

All these fields of inspection should indicate the frequency and inspection detail clearly. In addition to this, inspection should describe construction quality and ameliorate immediately if any defects found.

6.2.4 Rail Asset Information Requirement

6.2.4.1 Inventory Data

The inventory data of rail asset information shall be collected and managed for handover phase:

- rail identification, location and function descriptors
- structural information
- structure live load capacity
- electrical information, including rail signalling
- attachments, e.g. services/lighting
- environmental and historical listing
- geometric details, including alignment and clearances

6.2.4.2 Rail Design and Construction Data

The accurate collection and management of rail design information are related to the success of operation and maintenance stages. The following design data are required to handover rail asset management:

- approved drawings, including as-built drawings and any modified construction drawings
- cad files and models represent part or whole of approved design
- rail track information
- rail signalling information
- electrical system information
- baseline information
- design load capacity

During the construction phase, the construction data shall be recorded and submitted in the next stage to support asset management after project handover. Therefore, the following construction data shall be captured:

- construction date and cost
- special data
- track working record
- rail signalling installation record
- electrical system information
- photographs and video record

6.2.4.3 Inspection Records

At the stages of construction, operation and maintenance, and to ensure railway operation safety, both construction as well as regular inspection records should be managed and stored. Inspection records should not only be composed by structural elements, in terms of tracks and track foundation, but also comprised with mechanical and electrical systems.

6.3 Summary

This chapter defines the asset information and asset register requirements for assets over their lifecycle or portion thereof. This requirement describes the asset register, the creation and management of the asset information related to all assets owned and managed by and on behalf of authorities across the asset lifecycle.

Asset managers and maintainers are required to demonstrate that assets and related asset information is managed accurately and efficiently in accordance with the requirements of this standard. It sets high-level requirements for the asset register, associated asset data and documents over the lifecycle, and the asset information system. It also provides clarity of ownership of the asset information system, data and documents. Therefore, it ensures consistency, accuracy and completeness of asset information which supports and enables the transition to digital engineering (DE).

Considering that houses and buildings are constructed using similar materials and systems, there are few differences in the asset information required between housing and buildings. The overall asset management structure for houses is normally a subset of that for buildings due to the lower level of services used in housing assets. There will be differences in detail, both in describing asset components and maintenance activities, and also in meta-data descriptions of the assets. However, these could be handled within a single asset database system.

Initially, infrastructure projects appear to be significantly different to housing and buildings. However, many transportation assets contain specialised buildings – railways stations, bus shelters, etc. – and are built using similar materials and construction methods. The major difference lies in the size of infrastructure assets, the need to provide higher degrees of relative location references and the need to allow for the curvature of the earth in location specifications.

7 CONCLUSIONS

This report complements the other reports produced by this project - Digital Asset Information Management: A Guide and Manual and Digital Asset Information Management: Case Studies – by providing in depth information on various aspects of asset management information. This supports the more pragmatic information provided in the other two reports.

The brief discussion on asset management as a process is intended to indicate the complexity of the asset management process, including the wide range of stakeholders and the varying requirements of each of the stakeholders.

Asset data exchange standards are another complicated area. The IFC standard (buildingSMART, undated) provides an internationally recognised exchange standard for buildings for everything within the building façade. The site on which the buildings are located is less well catered for. There is the opportunity to harmonise the external works for buildings with the other areas of civil engineering. There are a wide range of standards available for civil assets. Many of these can be considered as "variations on a theme" where the basic information requirements are specified by different organisations. There are no technical reasons why these could not be harmonised. buildingSMART has made a start in this area, but progress has been slow.

Classification systems are necessary to provide structure to the information stored in an asset management database and to support queries from users that find and extract information from the database(s). Since the various disciplines involved in the design, construction and management of built assets have different concepts of the way that information about buildings and infrastructure are structured, and the differences between concepts, nomenclature and working relationships between different markets, it is not surprising that there are a number of alternative systems available for both buildings and infrastructure. An organisation that owns and/or manages assets needs to decide on the system that they will use to ensure consistent information storage and retrieval across their portfolio of assets.

Defining the location of assets is a difficult task. A range of alternative methods are presented in this report. The methods can be broken down into absolute references, where the location of each asset is defined with respect to an agreed datum, or relative locations that define the location of an asset, or component of an asset with respect to other assets, or the containing asset when dealing with parts. In practice, a mix of methods is normally required to suit the range of requirements of the users. Once again, asset owners or managers should select the location system(s) which best suit their way that the organisation works.

Asset information requirements need to be clearly defined before construction commences on a project to ensure that the necessary information is gathered during the construction process. The COBie process suggests that asset information should be recorded by the people responsible for installing the equipment and should be provided before they leave site. The integration of data capture with the installation process is intended to ensure that the information is as accurate as possible and is gathered in an efficient manner.

If asset management information requirements and gathering become an integral part of the design, construction and operation processes then asset management will become much more accurate and efficient.

APPENDIX A – CLASSIFICATION SYSTEMS FOR BUILDINGS: OMNICLASS TABLE 23 – PRODUCTS

Note 1: Under OmniClass "products" are things that are used in a building or structure, not necessarily a discrete item. Thus, products include the major structural, services, envelope and partition systems as well as fittings (built-in), equipment and furniture (whether built-in or not)

Note 2: The various building classification systems have attempted to be fairly general and support civil infrastructure systems to varying degrees. The harmonisation of the building and infrastructure classifications still needs to be done.

This appendix only shows the top 3 levels of the OmniClass Table 23 hierarchy. The full document runs to 109 pages (http://www.omniclass.org). There are 15 tables in OmniClass that cover other aspects of procurement and operation:

- Table 11 - Construction Entities by Function
- Table 12 - Construction Entities by Form
- Table 13 - Spaces by Function
- Table 14 - Spaces by Form
- Table 21 - Elements
- Table 22 - Work Results
- Table 23 - Products National Standard
- Table 31 - Phases
- Table 32 - Services
- Table 33 - Disciplines
- Table 34 - Organisational Roles
- Table 35 - Tools
- Table 36 - Information
- Table 41 - Materials
- Table 49 – Properties

The UK classification system, Uniclass, has a different structure, where the OmniClass "products" are spread across a number of tables:

Figure 0-1: Uniclass table hierarchy (https://toolkit.thenbs.com/articles/classification#classificationtables)

The two classification systems need to be compared with each other and with the NATSPEC tables (https://www.natspec.com.au/images/PDF/Worksection_Classification_List.pdf), although the NATSPEC tables are rather dated.

Level 1 Title	Level 2 Title	Level 3 Title
Site Products		
	Ground Anchorages	
	Ground Improvement Products	
	Sheeting and Revetments	
	Retention Structures	
	Slide and Avalanche Protection	
	Pavements	
	Parking Controls	
	Site Barrier Products	
	Landscaping	

Level 1 Title	Level 2 Title	Level 3 Title
	Site Furnishings	
	Athletic and Recreational Surfaces	
Structural and Exterior Enclosure Products		
	Loose Granular Fills, Aggregates, Chips, and Fibres	
	Binding Agents and Admixtures	
	Mixtures	
	Profiles	
	Sheets, Boards, and Slabs	
	Blocks and Bricks	
	Mechanical Fasteners, Adhesives, and Sealants	
	Thermal and Moisture Protective Products	
	Maintenance Products and Chemicals for Construction	
	Foundations	
	Structural Concrete Products	
	Envelope Enclosure Products	
	Framing Products	
	Multi-Function Exterior Coverings, Claddings, Linings	
	Roof Coverings, Claddings, Linings	
	Roof Specialties and Accessories	
Interior and Finish Products		
	Space Division Products	
		Fixed Partitions
		Demountable Partitions
		Sanitary Partitions and Cubicles
		Operable Partitions
	Multi-Function Interior Coverings, Claddings, Linings	
	Wall Coverings, Claddings, Linings	
	Floor Coverings	
	Ceiling Coverings, Claddings, and Linings	
	Surface Applied Coatings	
Openings, Passages, and Protection Products		
	Doors	
	Windows	
	Glazing	
	Skylights	
	Protection of Openings	

Level 1 Title	Level 2 Title	Level 3 Title
	Circulation and Escape Products	
	Circulation Guiding and Protection Products	
Specialty Products		
	Information Display Specialties	
	Lockers	
	Communication Specialties	
	Fireplaces	
	Flue and Chimney Products	
	Hearths	
	Kilns	
	Pest Control Devices	
	Manufactured Exterior Specialties	
	Complete Buildings	
	Room Units	
Furnishings, Fixtures and Equipment Products		
	Commercial Furniture	
	Retail and Office Equipment and Furnishings	
	Wardrobe and Closet Specialties	
	Interior Refuse Disposal Furniture	
	Casework	
	Food Service Equipment and Furnishings	
	Residential Furniture and Equipment	
	Educational and Cultural Equipment and Furnishings	
	Child Furnishings	
	Athletic and Recreational Equipment	
	Fitness and Exercise Equipment	
	Industrial and Manufacturing Equipment and Furnishings	
	Miscellaneous Equipment and Furnishings	
	Furnishings, Ornaments, and Decoration	
	Commercial Washing and Waste Disposal Equipment	
	Commercial Laundry Equipment	
	Cleaning Equipment	
	Historic Preservation Products	
	Musical Equipment	

Level 1 Title	Level 2 Title	Level 3 Title
Conveying Systems and Material Handling Products		
	Vertical Transportation Equipment	
	Lifting Equipment	
	Horizontal Transportation Equipment	
	Materials Handling	
	Turntables	
	Parking Systems	
	Loading Dock Equipment	
	Scaffolding	
Medical and Laboratory Equipment		
	Anaesthesiology and Respiratory Products	
	Audiology Products	
	Autopsy and Post-mortem Products	
	Dental Products	
	Dermatology Products	
	Emergency Trauma and Intensive Care Products	
	Endocrinology Products	
	Gastroenterology and Hepatology Products	
	General Internal Medicine Products	
	Therapeutic and Physical Therapy Products	
	Hematology Products	
	Medical Gas Products	
	Nursing Products	
	Obstetrics and Gynaecology Products	
	Ophthalmology Products	
	Orthopaedics Products	
	Otolaryngology Products	
	Patient Care Products	
	Patient Clinical Diagnostic Products	
	Patient Transportation and Lifting Equipment	
	Paediatrics Products	
	Pharmacology Products	
	Psychiatric and Psychology Products	
	Sterilization Medical Products	
	Surgical Products	
	Veterinary and Animal Products	

Level 1 Title	Level 2 Title	Level 3 Title
	X Ray and Imagery Products	
	Biological Protection and Preservation Products	
	Hazardous Materials Products	
	Laboratory and Scientific Products	
General Facility Services Products		
	General Instruments and Controls	
	Control and Monitoring Boards Panels	
	Building Automation and Control	
	Pumps	
	Engines	
	Compressors	
	Heat Exchangers	
	Heaters for Supplied Liquids	
	Pressure Reducing Stations	
	Tanks and Storage Structures	
	Valves	
	Valve Actuators	
	Variable Speed Drives	
	Liquid Traps	
	Piping	
	Pipe Repair Equipment	
	Pipe Fittings	
	Pipe Flanges	
	Pipe Adapters	
	Pipe Couplings	
	Pipe Elbows	
	Pipe Caps	
	Liquid Treatment Components	
	Gas Treatment Components	
	Recycling Equipment	
	Incinerators	
	Mechanical Insulation and Linings	
	Equipment Acoustic Insulation	
	Corrosion Proofing Equipment	
	Antivibration Mountings	
	Building Maintenance Equipment	
Facility and Occupant Protection Products		
	Security Detection and Monitoring	
	Security Access Controls	
	Secure Storage Structures and Products	

Level 1 Title	Level 2 Title	Level 3 Title
	Property Storage Locks	
	Chemical Biological Radiological Protection	
	Equipment for Security of Information	
	Fireproofing Components	
	Fire Fighting Equipment	
	Fire Ventilation Equipment	
	Fire Detection Devices	
	Fire Notification Appliances	
	Fire Suppression System Components	
	Fire Rescue Component	
	Occupational Safety and Health Equipment	
	Environmental Safety Equipment	
Plumbing Specific Products and Equipment		
	Faucets	
	Sinks	
	Bathtubs	
	Showers	
	Toilets	
	Urinals	
	Bidets	
	Toilet and Bath Specialties	
	Floor Drains	
	Hot Water Heaters	
	Drinking Fountains	
	Complete Sanitary Suites	
	Plumbing Tubing	
HVAC Specific Products and Equipment		
	Commercial Boilers	
	Furnaces	
	HVAC Heating Units	
	Heat Pumps	
	Cooling and Freeze Components	
	Chillers	
	Cooling Towers	
	Air Handling Units	
	Air Humidity Control Equipment	
	HVAC Dampers	
	Air Circulators	
	HVAC Fan Coil Units	
	HVAC Coils	
	Refrigerant Condensing Units	
	Air Conditioning Equipment	

Level 1 Title	Level 2 Title	Level 3 Title
	HVAC Air Terminals	
	HVAC Condenser Units	
	HVAC Coolers	
	Air Dryers	
	HVAC Ductwork	
	HVAC Specialized Equipment	
	Solar Water Heating Equipment	
	Energy HVAC Recovery Equipment	
Electrical and Lighting Specific Products and Equipment		
	Electrical Generators	
	Transformers	
	Electric Motors	
	Variable Speed Drives	
	Batteries	
	Battery Chargers	
	Power Conditioning Equipment	
	Electrical Instrumentation and Controls	
	Electrical Terminals	
	Circuit Breakers	
	Electrical Power Distribution Devices	
	Electrical Ducting Wireways Components	
	Electrical Contactors	
	Electrical Switches	
	Electric Power Protection Devices	
	Electrical Isolation Equipment	
	Electrical Relays	
	Non-Electrical Lighting	
	Electrical Lighting	
Information and Communication Specific Products and Equipment		
	Information Technology and Telecommunications Ducting Wireways Components	
	Information Technology Equipment	
	Audio Visual Equipment	
	Audio Information Equipment	
	Visual Information Systems	
	Audio Visual Systems	
	Telecommunications Equipment	
	Broadcasting Communications Equipment	

Level 1 Title	Level 2 Title	Level 3 Title
	Emergency Communications	
Utility and Transportation Products		
	Roadway Monitoring and Control	
	Tunnels and Bridges	
		Tunnels
		Bridges
	Railways	
	Funiculars	
	Aviation Equipment	
	Marine Construction Waterways and Seaways	
	Electrical Utility Equipment	
	Natural Gas Utility Equipment	
	Water Utility Equipment	
	Waste Water Collection and Removal	
	Packaged Waste Water Treatment	
	Water and Waste Water Preliminary Treatment Equipment	
	Water and Wastewater Chemical Feed Equipment	
	Water and Wastewater Clarification and Mixing Equipment	
	Water and Wastewater Secondary Treatment Equipment	
	Water and Wastewater Advanced Treatment Equipment	
	Water and Wastewater Residuals Handling and Treatment	
	Septic System Equipment	
	Offshore Structures	

APPENDIX B - MINIMUM ATTRIBUTES FOR COBIE DATA

These recommendations are based on the GSA requirements.

Attribute / Parameter	Data Type	Description	Responsible Party
COBie-Floor-CreatedBy	TEXT	The email address of the user who created the object.	Design team
COBie-Floor-Elevation	TEXT	Height above datum.	Design team
COBie-Floor-ExtSystem	TEXT	Information on the creating application.	Design team
COBie-Floor-CreatedOn	TEXT	Date the object was created.	Design team
COBie-Floor-Height	NUMBER	Floor to floor height.	Design team
COBie-Floor-Description	TEXT	Extended description of the object.	Design team
COBie-Floor-ExtIdentifier	TEXT	Information on the creating application.	Design team
COBie-Floor-Category	TEXT	Category of the floor (Site, Floor, Roof).	Design team
COBie-Floor-ExtObject	TEXT	Information on the creating application.	Design team
COBie-Floor-Name	TEXT	Unique name of the floor.	Design team
COBie-Space-ExtSystem	TEXT	Information on the creating application.	Design team
COBie-Space-Category	TEXT	Category of space. What kind of space is it? (OmniClass Table 13 Space Function)	Design team
COBie-Space-ExtObject	TEXT	Information on the creating application.	Design team
COBie-Space-UsableHeight	NUMBER	Used for COBie based data exchange.	Design team
COBie-Space-ExtIdentifier	TEXT	Information on the creating application.	Design team
COBie-Space-CreatedOn	TEXT	Date the object was created.	Design team
COBie-Space-FloorName	TEXT	Lowest floor in which space appears	Design team
COBie-Space-Description	TEXT	Extended description of the object.	Design team

Attribute / Parameter	Data Type	Description	Responsible Party
COBie-Space-GrossArea	NUMBER	Used for COBie based data exchange.	Design team
COBie-Space-NetArea	NUMBER	Used for COBie based data exchange.	Design team
COBie-Space-Name	TEXT	Unique space name primary key for all spaces.	Design team
COBie-Space-CreatedBy	TEXT	The email address of the user who created the object.	Design team
COBie-Space-RoomTag	TEXT	Room tag provides door number for building occupant	Design team
COBie-Zone-CreatedBy	TEXT	The email address of the user who created the object.	Design team
COBie-Zone-SpaceNames	TEXT	Used for COBie based data exchange.	Design team
COBie-Zone-ExtObject	TEXT	Information on the creating application.	Design team
COBie-Zone-Description	TEXT	Extended description of the object.	Design team
COBie-Zone-ExtIdentifier	TEXT	Information on the creating application.	Design team
COBie-Zone-Category	TEXT	Used for COBie based data exchange.	Design team
COBie-Zone-Name	TEXT	Used for COBie based data exchange.	Design team
COBie-Zone-CreatedOn	TEXT	Date the object was created.	Design team
COBie-Zone-ExtSystem	TEXT	Information on the creating application.	Design team
COBie-Type-WarrantyDurationUnit	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-ModelNumber	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-AssetType	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-WarrantyDescription	TEXT	Used for COBie based data exchange.	Construction team

Attribute / Parameter	Data Type	Description	Responsible Party
COBie-Type-WarrantyDurationLabor	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-Description	TEXT	Extended description of the object.	Construction team
COBie-Type-ReplacementCost	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-CreatedBy	TEXT	The email address of the user who created the object.	Construction team
COBie-Type-ExtObject	TEXT	Information on the creating application.	Construction team
COBie-Type-ExpectedLife	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-WarrantyDurationParts	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-WarrantyGuarantorParts	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-Category	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-WarrantyGuarantorLabor	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-DurationUnit	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-Name	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-CreatedOn	TEXT	Date the object was created.	Construction team
COBie-Type-Manufacturer	TEXT	Used for COBie based data exchange.	Construction team
COBie-Type-ExtSystem	TEXT	Information on the creating application.	Construction team
COBie-Type-ExtIdentifier	TEXT	Information on the creating application.	Construction team
COBie-Component-SerialNumber	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-Name	TEXT	Used for COBie based data exchange.	Construction team

Attribute / Parameter	Data Type	Description	Responsible Party
COBie-Component-TagNumber	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-WarrantyStartDate	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-ExtIdentifier	TEXT	Information on the creating application.	Construction team
COBie-Component-ExtSystem	TEXT	Information on the creating application.	Construction team
COBie-Component-TypeName	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-CreatedBy	TEXT	The email address of the user who created the object.	Construction team
COBie-Component-BarCode	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-InstallationDate	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-Description	TEXT	Extended description of the object.	Construction team
COBie-Component-CreatedOn	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-AssetIdentifier	TEXT	Used for COBie based data exchange.	Construction team
COBie-Component-ExtObject	TEXT	Information on the creating application.	Construction team
COBie-Component-Space	TEXT	Used for COBie based data exchange.	Construction team
COBie-System-ExtObject	TEXT	Information on the creating application.	Design team
COBie-System-CreatedOn	TEXT	Date the object was created.	Design team
COBie--Description	TEXT	Extended description of the object.	N/A
COBie-System-CreatedBy	TEXT	The email address of the user who created the object.	Design team
COBie-System-ExtIdentifier	TEXT	Information on the creating application.	Design team

Attribute / Parameter	Data Type	Description	Responsible Party
COBie-System-ComponentNames	TEXT	Used for COBie based data exchange.	Design team
COBie-System-ExtSystem	TEXT	Information on the creating application.	Design team
COBie-System-Category	TEXT	Used for COBie based data exchange.	Design team
COBie-System-Name	TEXT	Used for COBie based data exchange.	Design team
COBie-Attribute-SheetName	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-CreatedBy	TEXT	The email address of the user who created the object.	Shared
COBie-Attribute-CreatedOn	TEXT	Date the object was created.	Shared
COBie-Attribute-ExtSystem	TEXT	Information on the creating application.	Shared
COBie-Attribute-Name	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-RowName	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-ExtIdentifier	TEXT	Information on the creating application.	Shared
COBie-Attribute-Unit	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-Category	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-ExtObject	TEXT	Information on the creating application.	Shared
COBie-Attribute-Value	TEXT	Used for COBie based data exchange.	Shared
COBie-Attribute-Description	TEXT	Extended description of the object.	Shared

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