Architecture Framework (AF) Based Approach for Managing Complex Transport Projects

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Abstract. Transport infrastructure systems are very complex and expensive. Projects to procure such systems are costly, long and complex to manage. The procurement context usually includes many collaborating organizations but often with different concerns and priorities, and many interactions to other parties. This makes the procurement very complex and entangled. DoDAF, MoDAF and TRAK are three architecture frameworks (AF) that model the whole enterprise/system life cycle that includes system procurement. They are expressed as metamodels. In this paper, we analyse various procurements strategies and identify the concerns that AFs should address. The TRAK AF is then applied to a Rail procurement case study in collaboration with Transport for New South Wales (NSW) in Australia to assess its effectiveness in meeting the procurement needs. In all stages of the study, TRAK is mapped and compared to DoDAF and MoDAF to examine whether DoDAF or MoDAF can cover the inadequacies of TRAK. This paper shows that there is a considerable number of procurement needs which are overlooked by these architecture frameworks. It proposes a metamodel driven expansion to these frameworks to improve their completeness and expressiveness.

Keywords: Architecture Frameworks; System of Systems; Systems Analysis; Procurement; Complex Transport Systems; Architecture Modelling;

1. Introduction

Transport systems are critical facilities serving a country, city, or area, including the services and facilities necessary for its economy to function (Sullivan & Sheffrin, 2003). They include complex systems as roads, rails, tunnels, etc.. They can be defined as the physical components of interrelated systems providing commodities and services essential to enhance societal conditions and economic output (Skorobogatova & Kuzmina-Merlino, 2017) (Fulmer, 2009). A transport system is inherently a set of interrelated systems, aka system of systems (SoS) that aims to provide transport services to the public. The Government of the land is liable for the availability and quality of those services.

Transport systems around the world are increasingly expected to meet higher levels of performance, reliability and sustainability. In particular, there are clear trends to develop better integrated transport systems that recognize that commuters often engage several modes of transport to get to their destination (Shirvani, Perez, Campbell, & Beydoun, 2018). A higher level of knowledge and control of infrastructure "Systems of Systems" is increasingly required to manage their complex operation, maintenance and evolution. Projects defined to procure transport systems are costly, long and complex to manage. The context of transport projects typically comprises of many organizations with different concerns; each plays a particular role in this collaborative scenario, having many interactions to other roles, which further makes the procurement complex and entangled. The government is responsible for managing transport projects, so the public sector is responsible for establishing performance standards and ensuring that the concessionaire meets them. Local governments often lack the staff needed to plan, negotiate and monitor a contract that is suited to local circumstances and must spend significant resources acquiring the expertise and advice required. A 2007 report from the UK National Audit Office (UK National Audit Office, 2007) found that the average cost of external advice in procurement deals was just over £3 million per project. So, enhancing the procurement stage of the system lifecycle considerably contributes in cost reduction and the system development success in general. Indeed, we identify several challenges that are common to procuring large scale transport systems:

Systems of Systems Complexity. Each transport system can be considered a system of systems where individual lines not only form an independent system that transport people and freight through specified regions but also interact to transfer commuters between the lines. A wider view can be taken of the system to include multi-modal transport to include transfer between different modes of transport.

Significant Lag for Procurement. It can take 10-15 years to fully procure and put new facilities into service, during which time technology, standards and other relevant factors are likely to change, requiring modification to original contracts and financing arrangements.

Phased evolution on large parallel systems. Introducing new facilities into the transport system has to be phased in stages due to the size and complexity of the system and the need to not compromise the safety of the system. Tracking the configuration of the system at any stage is complex but much needed to ensure public safety and limited impact on commuters.

Environment-specific Issues and Requirements. Transport systems are typically distributed over a wide geographic region which causes further challenges in identifying, capturing and tracking of region-specific requirements. Stakeholder engagement for communication interfaces to monitor localized conditions is challenging.

Governments publish rules of procurements in guideline documents written in natural language. The rules serve to regulate the procurement context and to prescribe procurement methods. Despite the rigor and level of details in those documents, there exist many problems understanding, interpreting and consistently applying the rules prescribed in them (Shirvani, Scott, Perez, & Campbell, 2018). The procurement processes adhering to the rules generating additional amount of large documents e.g. to prepare the 'business case', 'request for proposal', and 'proposals' documents. Although guidelines typically suggest a standard format for the documents, the documents generated by both clients and contractors rarely follow a unified and standard structure. For instance, ambiguities and inconsistencies are often introduced in the procurement stages. Transactions can take longer and are often costlier due to documentation requirements and subsequent fixes. What is needed is a standard structure for knowledge sharing among various stakeholders. This can bring about a common understanding of the shared information. Towards this, this paper will identify common modelling requirements in a procurement process. The paper will assess how these common requirements are met with in approaches embodied in Architecture Frameworks (AFs). The paper focusses specifically on TRAK illustrating its limits in a Rail procurement transport case study in partnership with Transport for New South Wales (TfNSW). It aims to enhance the overall procurement process and to ensure the delivered transport system meets the desired levels of capability. The paper examines how Model Based System Engineering (MBSE) can be employed to enhance the procurement processes and any required evolution of the available languages and architecture frameworks to support them. The paper is organised as follows: Section 2 provides a background and an overview of Architecture Frameworks (AF). Section 3 provides an examination of procurement strategies. This highlights procurement requirements that need to be supported by an AF. Section 4 provides a case study to illustrate the strength and weakness of reviewed AFs. A representational gap analysis is then performed in section 5 and resolution steps and are proposed in Section 6. Finally, section 7 concludes with a discussion of the results and limitations of the study.

2. Background and related work

The procurement process of transport systems itself involves a complex system of organizations with different cultures and different concerns that perform different activities. However, all of the stakeholders share one common goal: developing a system that meets their requirements, addresses their interests and brings them values. **Error! Reference source not found.** illustrates the main stakeholders and their dependencies in the procurement domain; as shown all of them have interests in the transport infrastructure system. However, it has to be emphasised that the stakeholders concerns are not only about the transport system itself, but also about the procurement process of the system. System related concerns include the safety, security, performance and functionality of the system; while the procurement related concerns include the project costs, project risks, responsibility of the contract sides, project scheduling etc.

There are two types of approaches for tackling complexity in transport procurement projects. The first uses toolkits developed by expertise centres including The European PPP Expertise Centre (EPEC) Toolikt (The European PPP Expertise Centre, 2017), Public Private Infrastructure Advisory Facility (PPIAF) Toolkit (PPIAF, 2009), World Bank and AusAID Toolkit developed for Indian Ministry of Finance (Ministry of Finance Govt of India, 2017) and Asian Development Bank Toolkits (Asian Development Bank, 2011a, 2011b). These toolkits are structured documents accommodated (e.g. in webpages or excel files) designed to ease financial management of a project. Toolkits-based approaches are helpful to simplifying access, but they cannot assure generating consistent and complete procurement documents.

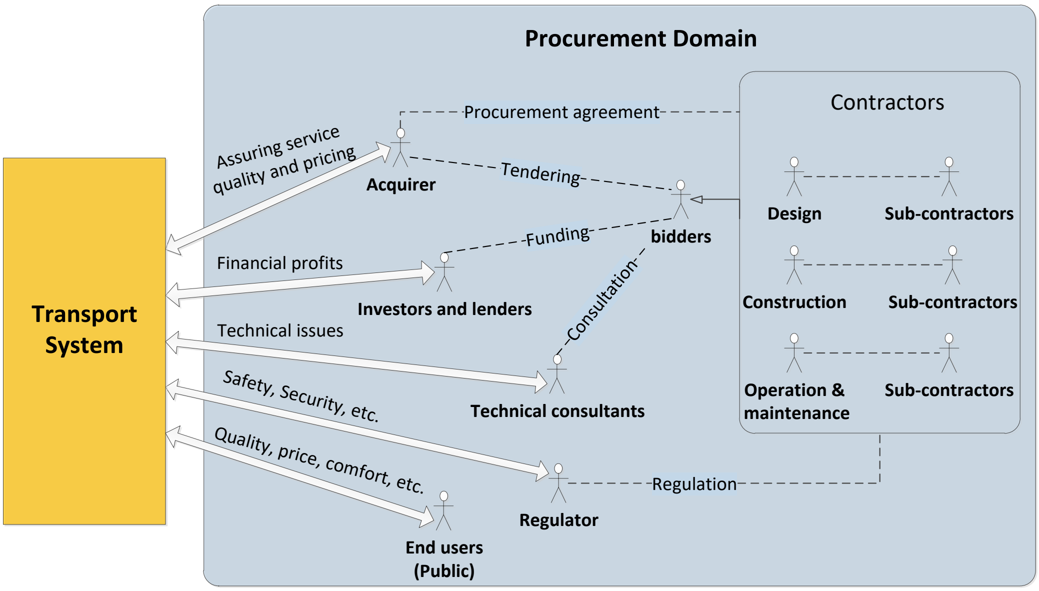

Figure 1: Procurement domain and the Transport system to be acquired

The second approach is based on Model Based Systems Engineering (MBSE). This approach facilitates systems engineering activities through development of standard and integrated models which provides a common understanding and results in enhanced communications (Friedenthal, Moore, & Steiner, 2009) (Othman & Beydoun, 2016) (Al-dhaqm et al., 2017). MBSE *"is the formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases"* (SE Handbook Working Group, 2011). In support of MBSE, model and data interchange standards support model and data exchange among tools (Delligatti, 2014; Holt et al., 2012) (Othman & Beydoun, 2010) . 'Architecture' is a fundamental model of a system showing how its key components are organised. It embodies the components, their relationships to each other and the environment, and principles governing its design and evolution (IEEE Std 1471, 2000). An Architecture Framework (AF) is a set of conventions and common practices for an architecture description established within a specific domain or stakeholder community (ISO/IEC/IEEE 42010, 2011). Tools are designed and implemented to comply with the rules of one or more modelling languages, enabling the practitioners to construct well-formed models in those languages. SysML (Systems Modelling Language; a UML profile) is the ADLs used to model acquisition AF artefacts in this paper. UML and SysML are the most commonly ADLs used to produce the models using AFs.

MBSE involves the following elements (Friedenthal et al., 2009) (Estefan, 2008) (Hause, 2006, 2010): Process Standard, Systems Engineering Method, Architecture Framework (AF), Architecture Description Language (ADL), Model and data exchange standard and a modelling tool. The Process Standards address broad industry needs and provide a foundation for the first step in practicing MBSE, identifying the fundamental processes of the domain of study. The Systems Engineering Method defines '*what*' activities are performed and how these are performed in terms of the types of artefacts that are produced and how they are developed. AFs identify and define the artefacts required for performing those activities. The artefacts are created as the inter-related concepts (a metamodel). While AFs identifies *'what'* to be modelled, Architecture Description Languages or modelling languages indicate *'how'* those artefacts should be modelled.

Modelling requirements for AFs must identify a set of stakeholders, a set of their architecture concerns, and a set of viewpoints framing those concerns. This ensures appropriate level of stakeholder involvement as advocated in (Miller, et al. 2014). An AF is comprised of a number Viewpoints (fragments of the metamodel), each framing a number of concerns AFs discussed in this paper are procurement oriented. They are developed by the defence sectors in the form of metamodels to provide a standardized knowledge structure for information sharing. These metamodels generate consistent and integrated models of both the 'system' and the 'procurement project' defined to procure the system.

The two most widely used architecture frameworks are the Department of Defense Architecture Framework (DoDAF) (US Department of Defense, 2010) in the USA and the Ministry of Defense (MOD) Architecture Framework (MODAF) (UK Ministry of Defence, 2013) in the UK (Hause, 2010). The AF called "The Rail Architecture frameworK" (TRAK) (Plum, 2012) has simplified MoDAF by keeping only the more generic elements of the metamodel. It omits the more specific ones which are treated as children of generic elements. TRAK has the breadth scope and completeness of MoDAF, but with less elaborated elements. Table 1 shows the viewpoints of the three mentioned AFs. Each table row represents a collection of viewpoints called Perspective. For instance, the Capability Perspective of DoDAF consists of three Capability viewpoints. Each viewpoint covers a stage of system life cycle and generates architecture views (models generated by the ADL) to address the concerns of one or more stakeholders. One of the issues in dealing with AFs is that there are several to choose between that are very similar with significant overlap. Different stakeholders often choose the AF that suits their needs which prevents a common representation (Shirvani, Effatmaneshnik, & Campbell, 2014).

Table 1: Viewpoints of Architecture Frameworks

TRAK	**DoDAF**	**MoDAF**
Enterprise (EV)	Capability viewpoints (CV)	Strategic Viewpoints (StV)
Concept (CV)	Operational Viewpoints (OV)	Operational Viewpoints (OV)
Procurement (PrV)	Project Viewpoints (PV)	Acquisition Viewpoints (AcV)
X	Services Viewpoints (SvcV)	Service Oriented Viewpoints (SOV)
Solution (SV)	Systems Viewpoints (SV)	Systems Viewpoints (SV)
Management (MV)	Standards Viewpoints (StdV)	Technical Standards Viewpoints (TV)
Management (MV)	All Viewpoints (AV)	All Viewpoints (AV)
X	Data And Information Viewpoints (DIV)	N/A

There is no current standard method for implementing architecture models created by AFs. To resolve this, UPDM (Hause, 2009; OMG, 2013) was introduced by Object Management Group (OMG®) (OMG, 2013) as the Unified Profile for DoDAF and MoDAF. UPDM is a Standardized way of expressing DoDAF and MODAF artefacts using OMG UML (Object Management Group, 2010a) and OMG SysML (Object Management Group, 2010b), as well as OMG XMI which is a standard for interchange. Standardization of model data and UML/SysML mapping means that both tool vendors and industry can provide models in a single format (Hause, 2010). In this research, we follow UPDM instructions in using the ADLs in architecture modelling and we select TRAK as the architecture framework for architecture modelling in our transport case study. We also map TRAK to the system lifecycle and compare it to DoDAF and MoDAF assess the efficiency and adequacy of all three frameworks. To analyse TRAK viewpoints and their contribution in systems engineering processes, they are mapped to the generic system life cycle (IEC/ISO 15288) (International Organization for Standardization/International Electrotechnical Commission, 2003) as depicted in Figure 2. The horizontal axis represents the stages of the system life cycle, while the vertical axis indicates the levels of enterprise hierarchy. The figure illustrates the 'Vee' lifecycle clearly.

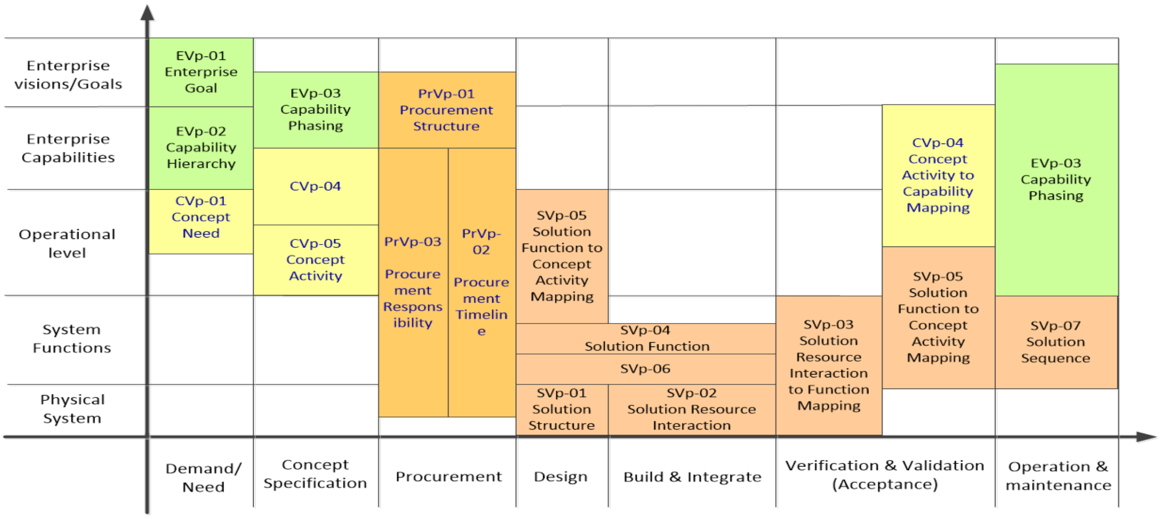

Figure 2: Mapping TRAK to System Lifecycle (IEC/ISO 15288)

3. Modelling Requirements and Method

A comprehensive procurement strategy that demonstrates careful consideration and analysis of all available options will enable project owners to identify the delivery model and suitable procurement methods. Project owners can then expect to attain improved value-for-money outcomes as risks will be most effectively managed and the incidence of contractual disputes, cost and time overruns are likely to be reduced (Scott, Shirvani, & Campbell, 2018). In this section, a list of prominent procurement methods and their suitability is provided based on a literature review on the results of best practice case studies (Department of Infrastructure and Transport, 2012) and government reports (Australia Department of Treasury and Finance, 2017; Department of Infrastructure and Planning Queensland Australia, 2010; Government of Western Australia, 2016; Hook; & Milazzo;, 2014; Infrastructure UK, 2013) (Australia Department of Defence, 2014). Six common procurement methods are typically recognised: Construct Only (CO), Design and Construct (DC), Design, Construct and Maintain (DCM), Construction Management (CM), Public Private Partnership (PPP) and Alliance Contracting (AC). The first four are called conventional methods which are naturally adversarial. The last two are becoming more common and are non-adversarial. Each of these methods is described and analysed in Appendix A. The analysis leads to identifying the following fourteen procurement requirements:

1. Enterprise goals & strategies:
2. User requirements
3. System Services
4. System requirement specifications
5. System functions and physical models
6. Compliance with the regulatory standards
7. System V & V
8. Operation and Maintenance plans
9. Project costs and finances
10. Project feasibility and viability
11. Quantitative bid evaluation (VFM and PSC models)
12. Risk definition & allocation
13. Organizational interconnectivity
14. Contract management and dispute resolution

In order to have a complete model of a transport procurement project, the architecture framework has to support modelling of all of the above mentioned requirements (Shirvani, Scott, Kennedy, Rezaeibagha, & Campbell, 2019). This paper applies TRAK to generate an architecture model of a rail procurement project (Transport for NSW - RailCorp, 2012) to examine the completeness of this AF. As mentioned earlier, architecture modelling relies on identification of the stakeholders, their concerns and the model views for addressing those concerns. In this paper we adopt the architecture modelling process suggested by ISO42010 standard (ISO/IEC/IEEE 42010, 2011). Figure 3 shows terms used in an architecture modelling and their relationships according to the IEEE 42010 standard. The steps of the process are as follows:

1. Identifying the stakeholders who are concerned about the system of interest
2. Identifying the concerns of each stakeholder
3. Identifying the AF viewpoints required for addressing the concerns
4. Populating the viewpoints with proper information to generate the model views

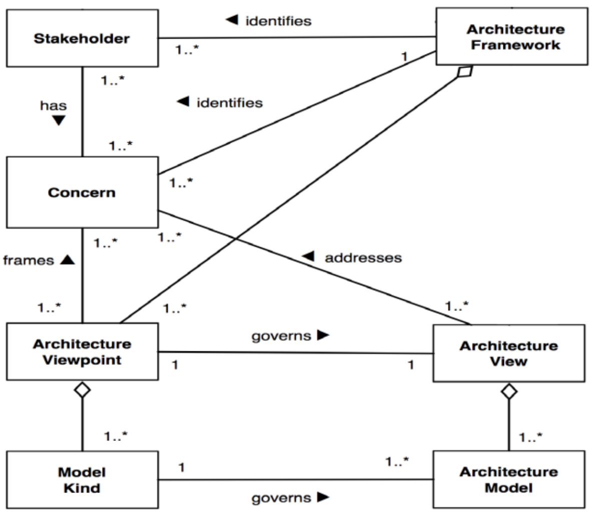

Figure 3: The relationship between architecture description terms

To model a real procurement project as a case study, a Public Private Partnership contract (Transport for NSW - RailCorp, 2012) provided by Transport for NSW is selected. There are two reasons for selecting this contract for the case study; first, as indicated in Table A.1, the PPPs are complex contracts and involve all the fourteen procurement requirements. Selecting a PPP contract thus allows us to challenge the completeness of architecture frameworks and highlight the gap in their adequacy to meet all information requirements. The second reason is practical. PPP contract documents are actually publicly available. Governments reveal all non-confidential documents of the PPP contracts to comply with transparency and impartiality policies. Next section explains how TRAK, as an architecture framework, is used to model this procurement project and highlights where TRAK falls short.

4. Case Study: Procurement in Transport for NSW

In investigating the adequacy of AFs to model information required during procurement, a populated model and corresponding views were developed. The first step in the development of an architecture model is identifying the stakeholders and their concerns. This activity identifies the information that has to be captured and directly relates it to the context of the situation. This has been done in the context of transport projects undertaken by Transport for New South Wales (TfNSW).

4.1 *Stakeholder Concerns and Architecture Viewpoints*

Transport for NSW is responsible for improving the customer experience, planning, program administration, policy, regulation and procuring transport services. It has six core divisions plus four operating agencies that realize the operational goals of TfNSW (Transport for NSW, 2015). These core divisions are the Customer Experience (CE), the Freight and Regional Development (FRD), the Planning and Programs (PP), the Transport Projects Division (TP), the Policy and Regulation (PR) and the Transport Services (TS). The PP division and TP were selected as the exemplar users of the architecture in this paper as they are directly involved in the early stages of the asset lifecycle. AEOs (Authorized Engineering Organization) are selected as the third main stakeholder of the architecture as they are responsible for design, construction and sometimes operation of the assets. One view is created for each of the stakeholders, as follows:

Planning and Program division. This is responsible for providing consolidated planning and overall investment advice for all modes. They are mainly involved in goal definition, feasibility analysis and the conceptualization phase of the asset life cycle. As shown in Figure 4 they are concerned with high level issues of the enterprise as goals (EV-01), capabilities (EV-02 and EV-03) and high level concepts (CV-01, CV-04 and CV-05) of the enterprise activities.

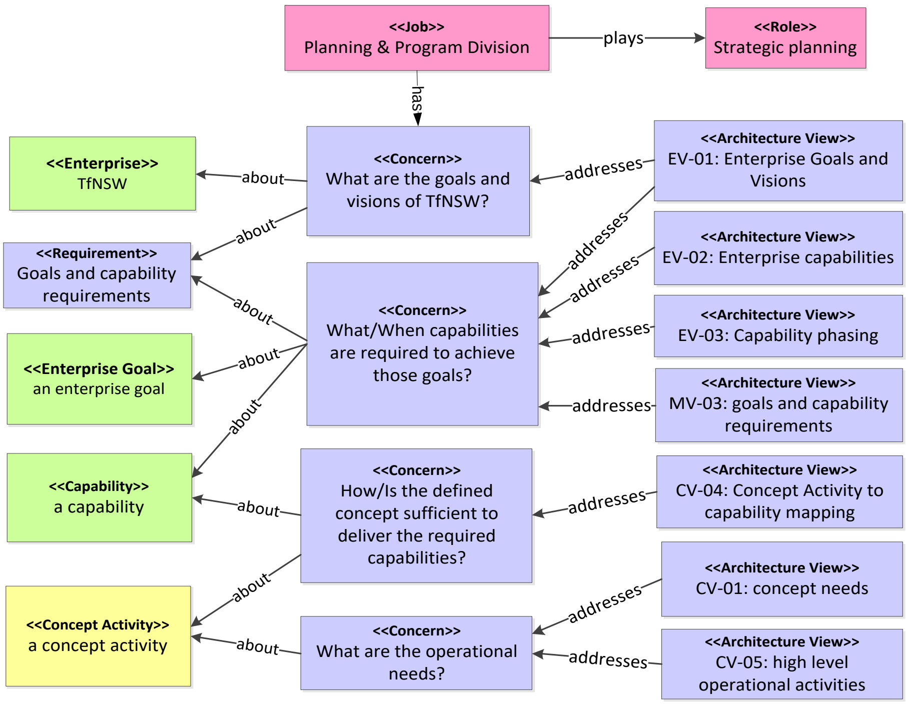

Figure 4: Planning and Program Division Notional Concerns and Views

Transport Projects. TP works in partnership with service providers and the construction industry to deliver innovative and sustainable transport networks. A customer focus is followed to offer value for money to the people of NSW (Tranport for NSW, 2012). Operational activities are defined in CV-05 (often called “user requirements” shown in MV-03) which should be delivered by the assets to support the higher level concepts and therefore the required capabilities. Then the functions realizing those operational requirements will be defined using (SV-05) to provide a more transparent expression of the services that the procured solution (system/asset) is expected to provide. Therefore, the operational requirements together with defined functions (functional requirements) will be passed to the bidders in the tendering process to be negotiated with the Contractor Organizations. The structure and timing of the procurement project would then be managed by PrV-01 and PrV-02. TP is also concerned with authorizing the potential contractors by assessing their competency in delivering specific functions (SV-06). The authorized organizations will be called AEOs and their concerns are shown in Figure 5.

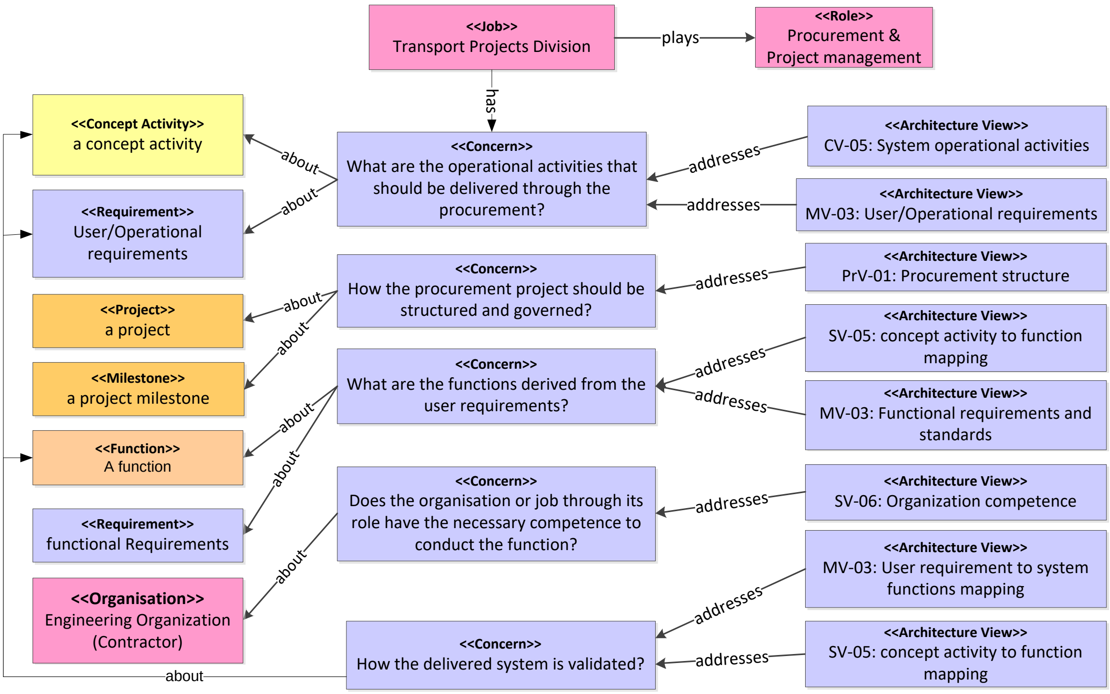

Figure 5: Transport Projects Division Notional Concerns and Views

Engineering Organizations. As mentioned above EO refers to the organizations that contribute in delivering the assets to TfNSW through contracts. Figure 6 shows their concerns and the addressing views. They receive the user requirements and required functions from the acquirer (TPD) to design the solution which best satisfies their requirements. Obviously, the solutions functions will be refined and redefined through negotiations to be finalized and recorded in SV-04. The solution structure consisting of the functions, system (Software and Physical parts) and human resources is defined in SV-01 and SV-02. The system verification is a main concern of EOs addressed by SV-03.

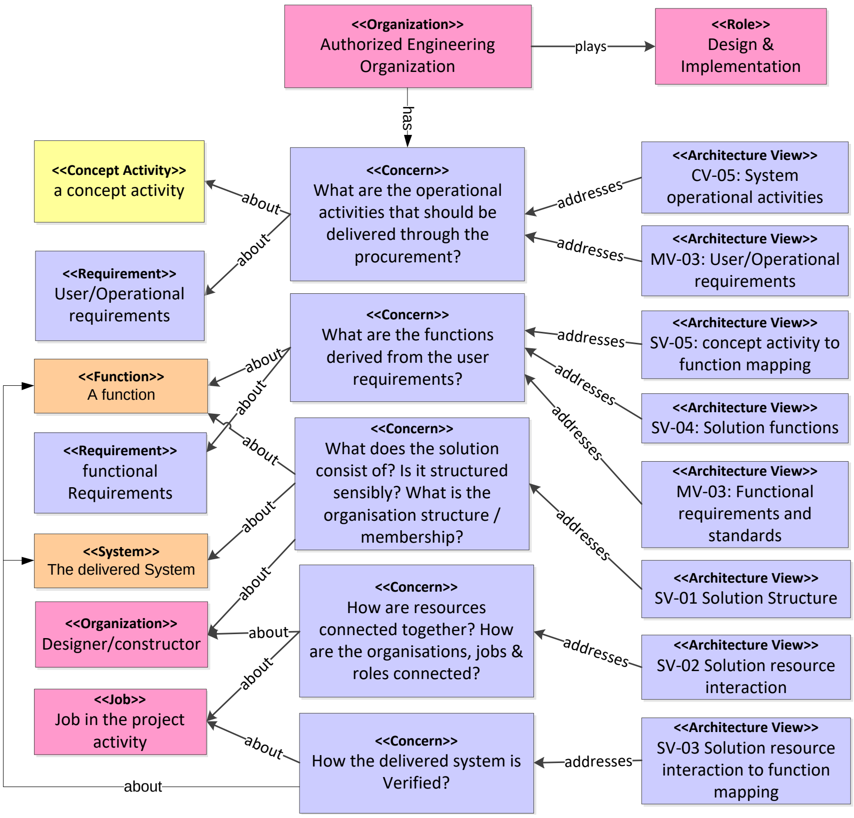

Figure 6: Engineering Organizations Notional Concerns and Views

4.2 *Generating views (models) conforming to identified viewpoints*

Once the stakeholders and their concerns are identified, we need to select the proper viewpoints and populate them with the real information to generate the architecture model. In this section, the modelling practice attempts to cover all the fourteen procurement requirements by generating the architecture views. Five views namely EV-02, CV-04, CV-05, SV-05 and MV-03 are selected from TRAK which cover the system specific concerns (requirements 1 to 8). However, some of the requirements cannot be covered by TRAK due to lack of viewpoints for those concerns. These requirements are shown in the diagrams as a gap box to clarify the missing elements.

EV-02 Enterprise capabilities. This view provides a way of describing the enduring capabilities needed to meet the enterprise's goals and the dependencies between them. It also provides the means to create a hierarchy or taxonomy structure for capabilities. The respective viewpoints of UPDM illustrate this viewpoint by block diagrams as shown in Figure 7.

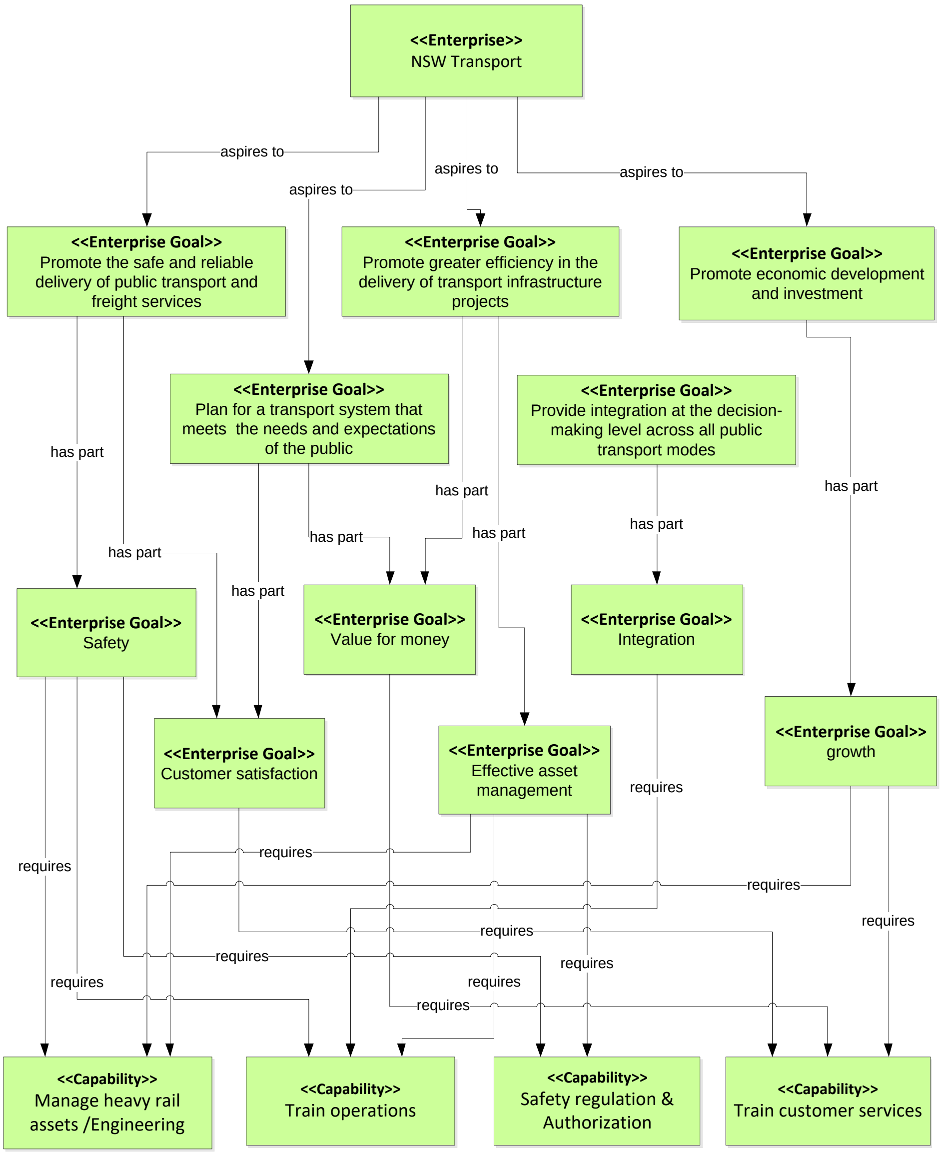

Figure 7: TRAK::EV-02 Enterprise capabilities

CV-04 Concept activity to capability mapping. This view provides a trace from the Concept Activity to the Enterprise capabilities supported by those concept activities. So, the capabilities shown in Figure 8 are mapped to the concept activities in this view. The respective UPDM viewpoint to this view is StV-6 Operational Activity to Capability Mapping (OMG, 2010) shown in

Table 2.

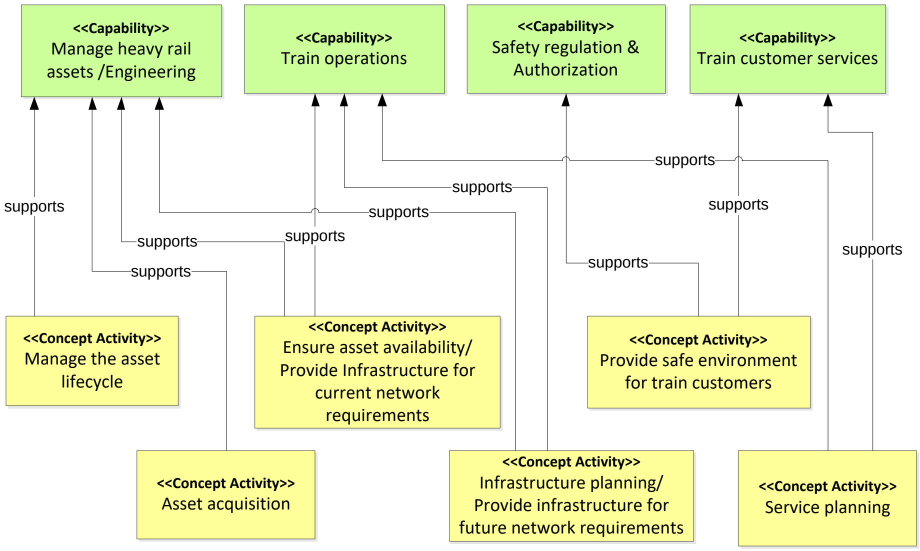

Figure 8: TRAK::CV-04 Concept activity to capability mapping

Table 2. UPDM::StV-6 Operational Activity to Capability Mapping

		Capability			
		Manage heavy rail assets /engineering	Train operations	Safety regulation & Authorization	Train customer services
Concept activity	Manage the asset lifecycle	x			
	Asset acquisition	x			
	Ensure asset availability/ Provide Infrastructure for current network requirements	x	x		
	Infrastructure planning/ Provide infrastructure for future network requirements	x	x		
	Provide safe environment for train customers			x	x
	Service planning		x		x

CV-05 high level operational activities. This view identifies the activities conducted by concept nodes as part of an implementation-free description of the overall concept. In UPDM the operational activities can be shown in 4 different forms OV-1a to OV-1d. OV-1d illustrates the operations by use cases which is the most useful and standard way of showing them (OMG, 2010). This view is shown in Figure 9.

SV-05 Concept activity to function mapping. The SVp-05 provides the means to map functions from parts of the solution to the implementation-free concept activities. In doing so it provides a) justification for the solution functions b) ensures that there is nothing behavioural in the concept perspective that isn't addressed within the solution and c) ensures that there is no unwanted functionality in the solution. TRAK::SV-05 can be mapped to UPDM::SV-5 Function to Operational Activity/Service Function Traceability (OMG, 2010) which is shown in table format. Figure 10 illustrates this view and similar to CV-04 it can be shown by a matrix as well.

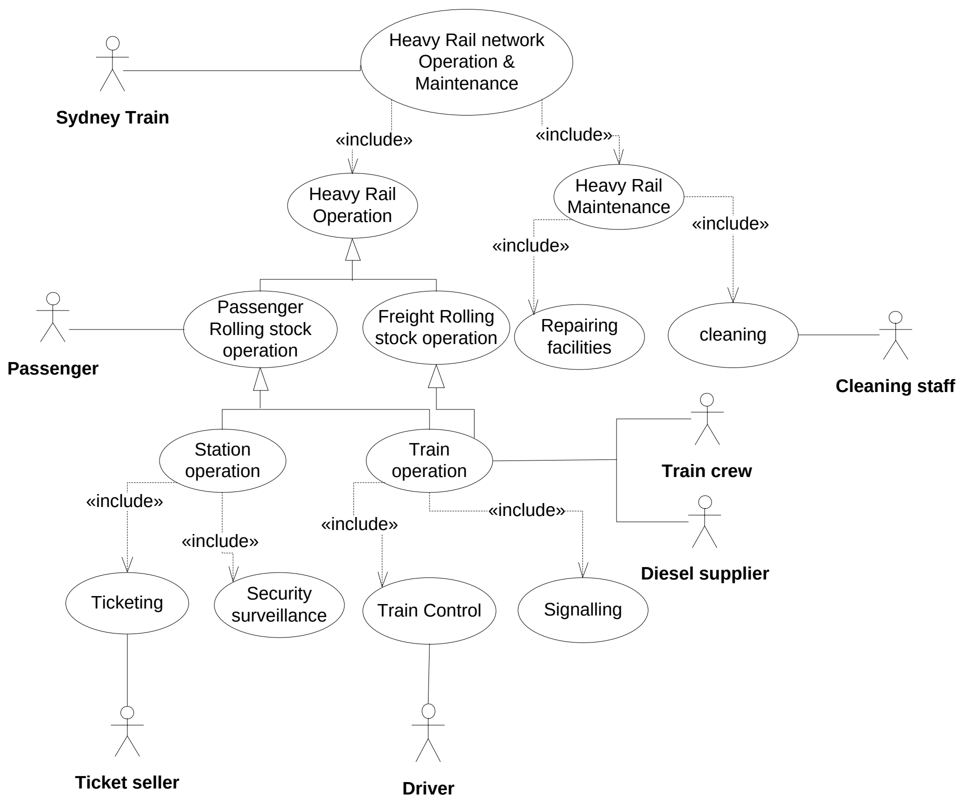

Figure 9: UPDM::OV-1d Operational Context modelled by SysML Use Case diagram

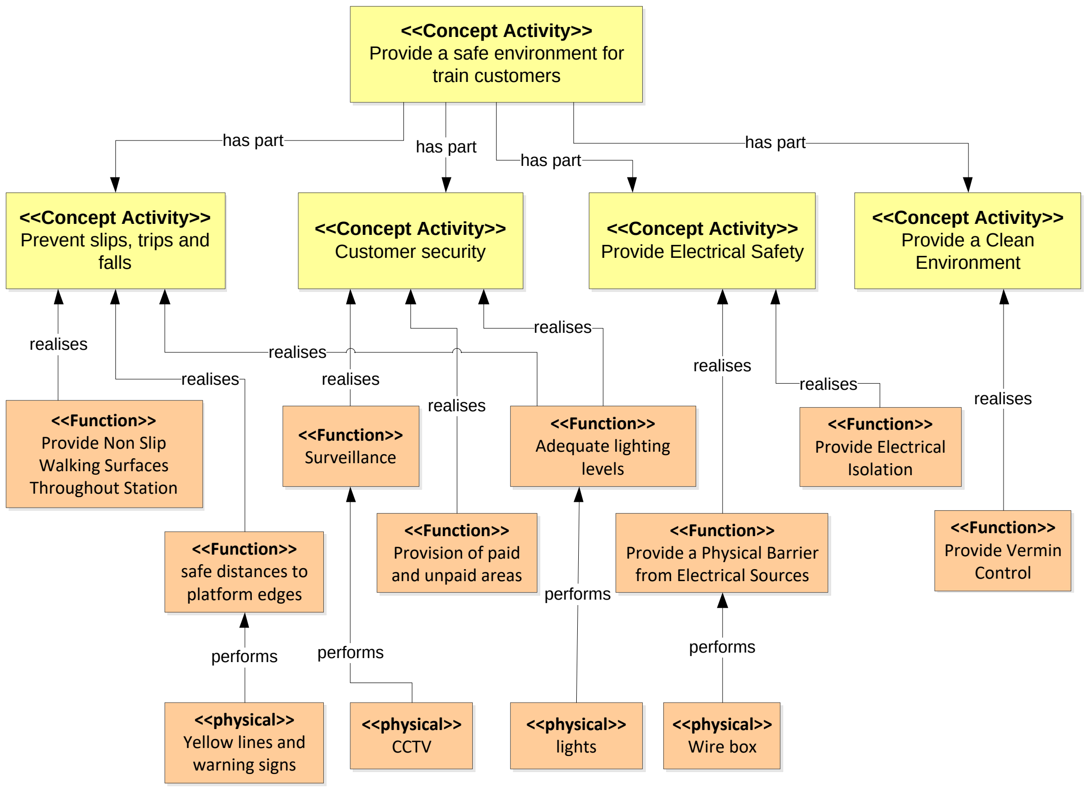

Figure 10: SV-05 Concept activity to function mapping

MVp-03: Requirements and standards. A major concern and huge effort and cost element of any complex major infrastructure project is the need and requirement to address the many standards which apply. This viewpoint provides a way of capturing normative requirements whether standards, requirement documents, government acts, or individual requirements. The views produced are expected to focus primarily on standards or on requirements. Requirement-focussed views will make it possible to show how the architecture description links to products from requirement management tools such as DOORS (Dynamic Object Oriented Requirements System) and also act as a justification for the way in which the architecture has been represented in the architecture description. It is not the purpose of an architecture framework to manage requirements. It is the purpose of TRAK to provide a means of integrating architecture description with dedicated requirement management tools (Plum, 2012).

UPDM uses SysML requirement diagrams for recording the requirements and standards and for keeping their connections to other architecture elements (OMG, 2010). The connection «trace» is used when an element is generating or is tracing to a requirement/standard. «refine» connection is used to indicate that a model element is a refinement of a textual requirement/standard (Friedenthal et al., 2009). In this view a capability is defined to refine the 'Transport Administration Act 1988" which explains the goals of Rail Corp. This capability generates the standard "ESB 000' which is refined by three concept activities. This trace goes down to the function level only in this view; however, the functions will generate the functional requirements which will be refined by the systems (consisting of physical and software) from which the system requirements are generated. The system requirements will be used as system specifications by system developers in design and implementation. In UPDM there are a variety of viewpoints for showing the requirements and standards including OV-6a Operational Rules Model, SV-10a System Rules and Constraints and TV-1 Standards Profile. Table 3**Error! Reference source not found.** shows the standards used in Figure 11 in a table format which is called standards profile.

Table 3. UPDM: TV-1 Standards Profile

		Standards				
		Crime Prevention through Environmental Design (CPTED)	Disability Discrimination Act 1992 (DDA)	Building Code of Australia (BCA)	AS2220.2 Emergency warning and intercommunication systems in buildings	Occupational Health and Safety Regulation 2001
Conforming elements	« Concept Activity » Provide a secure environment for train customers	x		x	x	
	« Concept Activity » Provide a safe environment for train customers	x	x	x	x	x
	« Concept Activity » Enabling all customers including those with disabilities to equitably access all public facilities		x	x		x

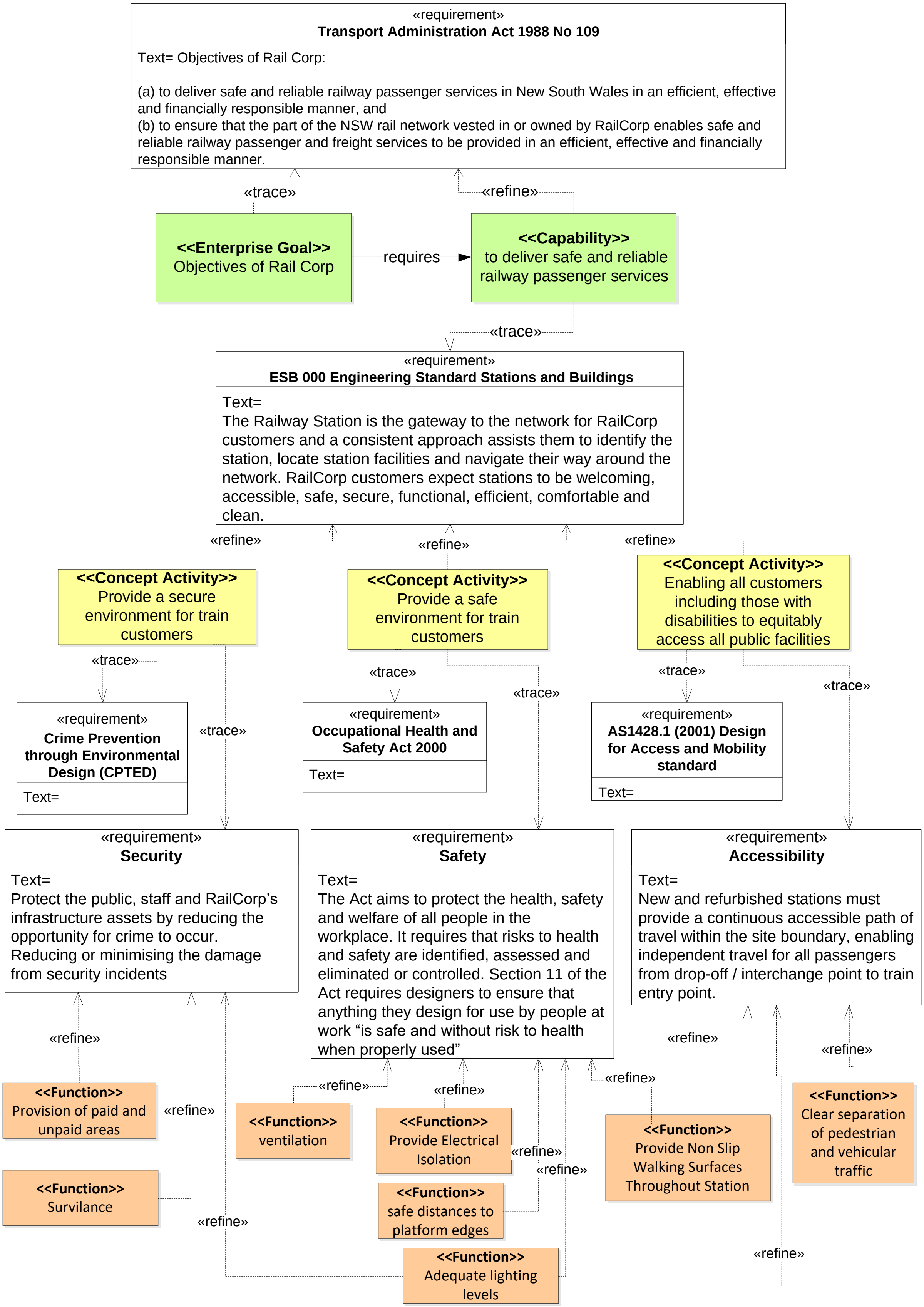

Figure 11: MV-03 requirement hierarchy modelled by SysML requirement diagram

Project Costs: Once the main operational concepts, systems functions and system physical parts are identified, the cost of construction, operation and maintenance of those services are estimated. The existing AFs lack the elements to accommodate the cost estimation models of a procurement project which shows a gap in the frameworks. The cost related concerns are indicated in Figure 12.

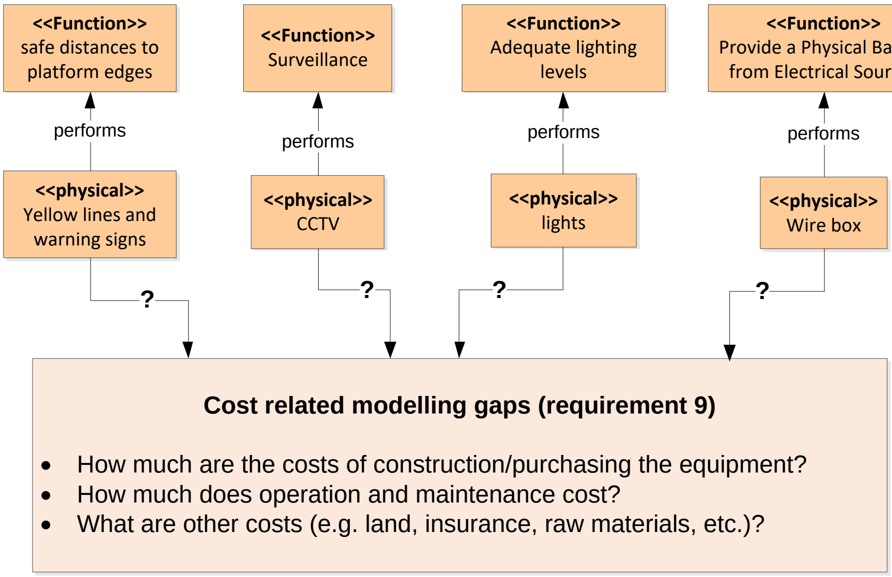

Figure 12: Cost related modelling gaps

Project Risks: Another main concern of the transport systems is identifying risks involved in operation of the system and managing them. Yet, current AFs do not provide means for identification of the safety and security risks and managing them. The risk related modelling gaps are shown in Figure 13.

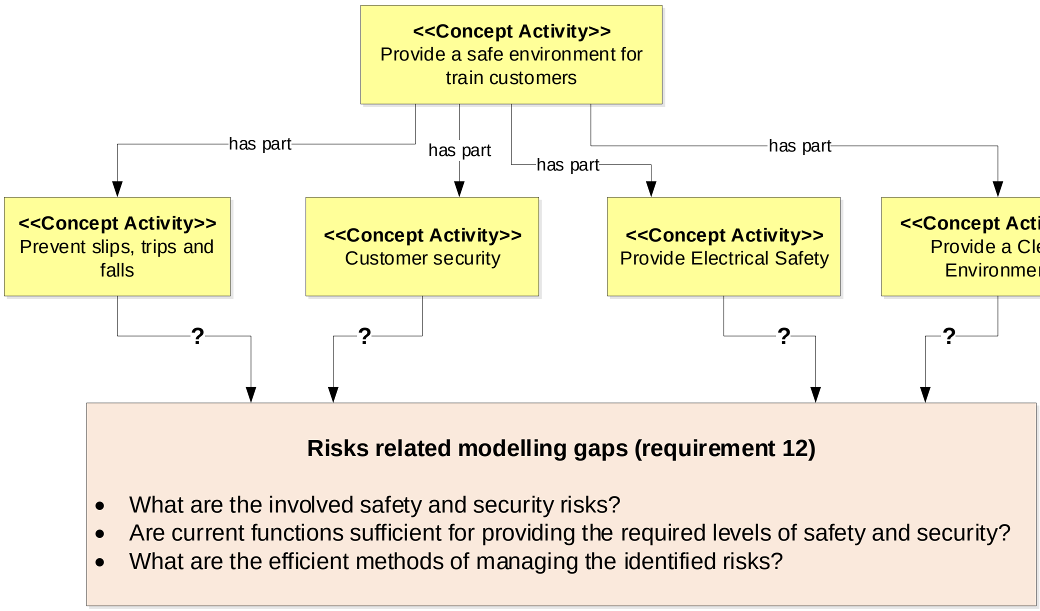

Figure 13: Risk related modelling gaps

Project assessment and contract management: According to the identified strategies of the TfNSW, they need to promote the economic development and investment. This requires the ability of quantitative assessment of the project. This is indeed aligned with the identified procurement requirements. However, the architecture frameworks do not support modelling the quantitative assessment and feasibility and viability assessment of the projects which is a considerable gap (as shown in Figure 14).

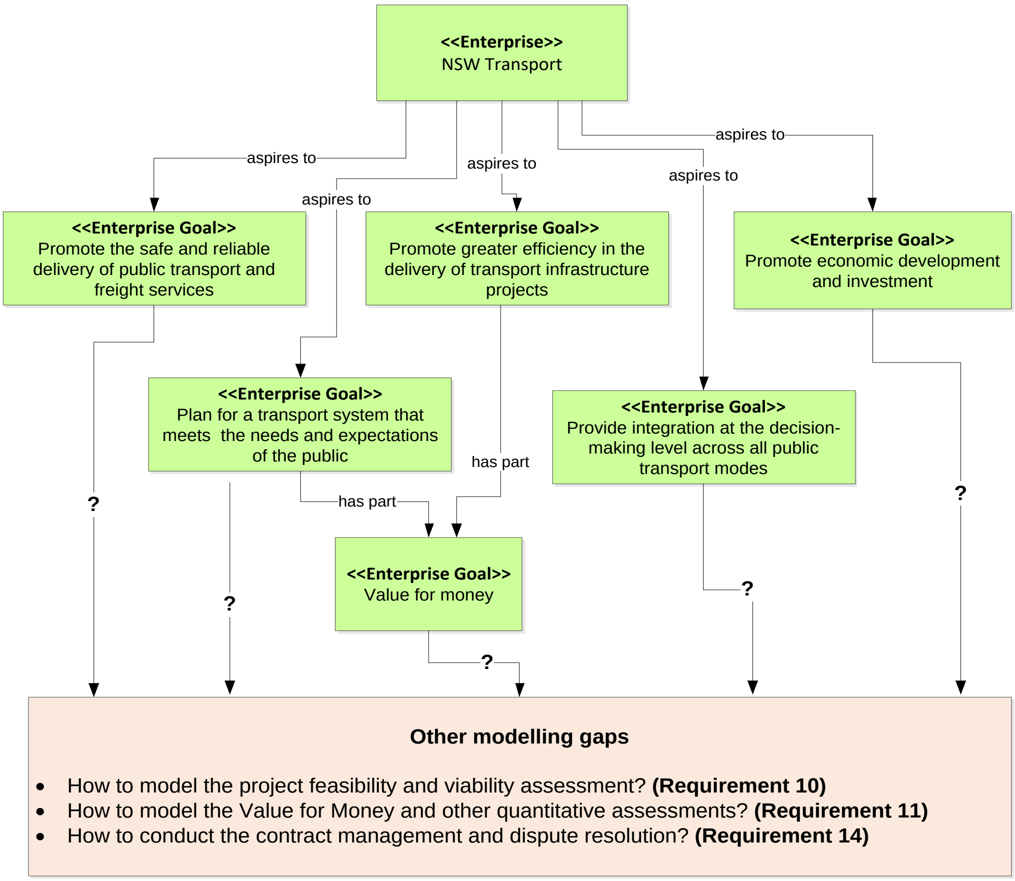

Figure 14: The requirements not supported by the AFs

5. Gap Identification

As mentioned earlier, this research throws a light on procurement of infrastructure systems and how MBSE methods can be applied to bring more transparency into them. Architecture frameworks are modelling conventions and instructions to model both system specific concerns and system procurement concerns. The applications of architecture frameworks in the rail case reflects the fact that the system specific concerns, such as user requirements, system services, physical and functional aspects of the system, are fully or partially covered by the current architecture frameworks. However, the concerns related to the '*procurement of* the system' such as financial aspects of the project, project risks, bid evaluation and dispute resolution are mainly overlooked. The results of this gap analysis, which are based on the case study lessons, are summarized in Table 4. In order to further clarify this representational gap, the procurement/project/acquisition viewpoints of the three discussed architecture frameworks (TRAK, DoDAF and MoDAF) are shown in Table 5.

Table 4: Mapping the procurement requirements to the AFs viewpoints to highlight the gaps

Procurement Requirements	TRAK Viewpoint	DoDAF Viewpoint	MoDAF Viewpoint	Requirement fulfilment
1. Enterprise goals & strategies	Enterprise (EV)	Capability (CV)	Strategic (StV)	Fully
2. User requirements	Concept (CV)	Operational (OV)	Operational (OV)	Fully
3. System Services	X	Service (SvcV)	Service Oriented (SOV)	Fully
4. System requirement specifications	Solution (SV)	Systems (SV)	Systems (SV)	Partially
5. System functions and physical models	Solution (SV)	Systems (SV)	Systems (SV)	Fully
6. Compliance with the regulatory standards	Management (MV)	Standards (StdV)	Technical Standards (TV)	Fully

7. System V & V	Concept & Solution	Operational &Systems	Operational & Systems	Partially
8. Operation and Maintenance plans	Concept	Operational	Operational	Partially
9. Project costs and finances	X	X	X	X
10. Project feasibility and viability	X	X	X	X
11. Quantitative bid evaluation (VFM and PSC models)	X	X	X	X
12. Risk definition & allocation	X	X	X	X
13. Organizational interconnectivity	Procurement (PrV)	Project (PV)	Acquisition (AcV)	Partially
14. Contract management and dispute resolution	X	X	X	X

Table 5: (Procurement) Project viewpoints of architecture frameworks

TRAK	**DoDAF**	**MoDAF**	**Description**
PrVp-01: Procurement Structure	PV-1: Project Portfolio Relationships	AcV-1: Acquisition Clusters	It describes the dependency relationships between the organizations and projects and the organizational structures needed to manage a portfolio of projects.
PrVp-02: Procurement Timeline	PV-2: Project Timelines	AcV-2: Programme Timelines	A timeline perspective on programs or projects, with the key milestones and interdependencies.
X	PV-3: Project to Capability Mapping	X	A mapping of programs and projects to capabilities to show how the specific projects and program elements help to achieve a capability.
PrVp-03: Procurement Responsibility	PV-1: Project Portfolio Relationships	AcV-1: Acquisition Clusters	Describes the extent of a role at a point in time.

The Project models developed by these viewpoints can be used to answer questions such as:

- What capabilities are delivered as part of this project?
- Are there other projects that either affect or are affected by this project? To what portfolios do the projects or projects belong?
- What are the important milestones relative to this project? When can I expect capabilities to be rendered by this project to be in place?

The information depicted by Table 5 expresses the capabilities of the procurement viewpoints of current architecture frameworks and therefore emphasises the inadequacy of them in meeting the identified requirements.

Rich Hilliard, the editor and chair of ISO/IECIEEE 42010, has published the lessons learnt during development of this standard (Hilliard, 2012). He says, “The most important lesson learned from the past 20 years of architecture framework development is this: you will never finish defining the ontology of a given domain of interest”. In another paper (Emery & Hilliard, 2009) he writes “For any of the numerous published frameworks, it is trivial to identify gaps in their polished metamodels. A fixed ontology is a luxury not borne out by previous frameworks.” The ontology of frameworks has evolved as our understanding of enterprises, information systems and software has evolved. Rich Hilliard writes “The earliest frameworks knew nothing of object-oriented programming and design; later frameworks invariably included objects. Early frameworks did not include notions like service—yet, no self-respecting framework today would ignore service-oriented architecture. There is no reason to believe this evolution will not continue. An architecture framework is—at best—a ‘‘starter set’’ of Concerns, Stakeholders, Viewpoints and Model Kinds for Architects within the domain of interest” (Emery &

Hilliard, 2009). Thus the developer of an architecture framework needs to consider the known and likely stakeholders for systems and architecture descriptions of systems. These stakeholders motivate the set of architecture-related concerns that the architecture framework will focus upon. A conforming architecture framework must identify these architecture-related concerns. Identifying the concerns to be addressed leads directly to the choice of viewpoints to be included.

6. Discussion and Future Work

As concluded in the previous sections, the current metamodels of the existing AFs (TRAK, DoDAF and MoDAF) are not capable of covering procurement domain completely and therefore are not capable of addressing all of the concerns of the stakeholders. The future steps of this research aim at extending the AFs by adding the missing elements to their metamodels which enables them to support a wider range of stakeholders' requirements.

As discussed in section 2, UPDM metamodel is developed by combining and reconciling the DoDAF and MoDAF metamodels and is implemented as a profile of UML and SysML. To keep pace with the trends of AF developments, the extensions are proposed to also be added to UPDM both to the metamodel and to the profile. In the other words, the extensions will be in the form of a metamodel and will be implemented as a SysML profile which forms a domain specific language (DSL) for transport procurement. The DSL can be used together with UPDM to cover both the system and its procurement concerns. According to what discussed, the requirements of the procurement DSL can be listed as follows:

1. Integration to the UPDM: The domain metamodel and its profile should not be created in isolation, but the profile will be integrated to the body of UPDM, as a unified internationally accepted profile. The fragments of this metamodel (viewpoints) should be connected and traced to UPDM viewpoints.
2. Metamodel implementation: The metamodel is implemented as a SysML profile. Its elements are specializations of SysML elements.
3. The domain specificity: Whilst the metamodel is to be specific to transport contracts, it still has to be independent of any contract type, project, country.
4. Compliance with the standards: The metamodel has to conform to the ISO42010 standard, so it should be created based on the instructions of this standard.
5. Content of the metamodel: the metamodel needs to include elements to support modelling of procurement requirements not currently covered (e.g. Costs and Finance, Risks, etc.)

Figure 15 illustrates how this DSL fits into the context of current literature. As shown, UPDM consists of a metamodel (abstract syntax) which is mapped to a profile (concrete syntax). The UPDM profile is a group of stereotypes which are specializations of UML and SysML. Likewise, the DSL has a metamodel that expands the UPDM metamodel (adds new concepts to it); and is mapped to a profile which is specializations of (i.e. extends) SysML. The use of domain related constructs to validate the requirements will be facilitated as advocated in (Lopez-Lorca et al. 2016; Beydoun et al. 2011; Wang et al 2013). The process for developing the metamodel and implementing the profile is tailored by reviewing and combining a number of other metamodeling methods as described in (Shirvani, et al. 2019). The steps of the process are as follows:

Metamodel development:

1. Knowledge gathering: collecting the guidelines and regulations about transport procurement. These need to be collected from the international procurement agencies and the department of transport of a variety of countries to assure the metamodel is nation agnostic
2. Concept extraction: analysing the documents to identify and collect the domain constructs concepts.
3. Concept relationships: identifying the relationships between the extracted concepts to form the domain ontology

4. Metamodel evaluation: applying different forms of test to verify and validate the metamodel (testing its completeness, conciseness, applicability, etc)
5. Linking to UPDM metamodel: checking the potential dependencies of the metamodel elements to the UPDM profile and define the required linkages

Profile development:

1. Stereotype definition: defining the metamodel elements and their dependencies as SysML stereotypes.
2. Diagram frames: This to accommodate the newly created stereotypes.
3. Process guide: This to help the modellers with using the new diagrams for generating the procurement models.

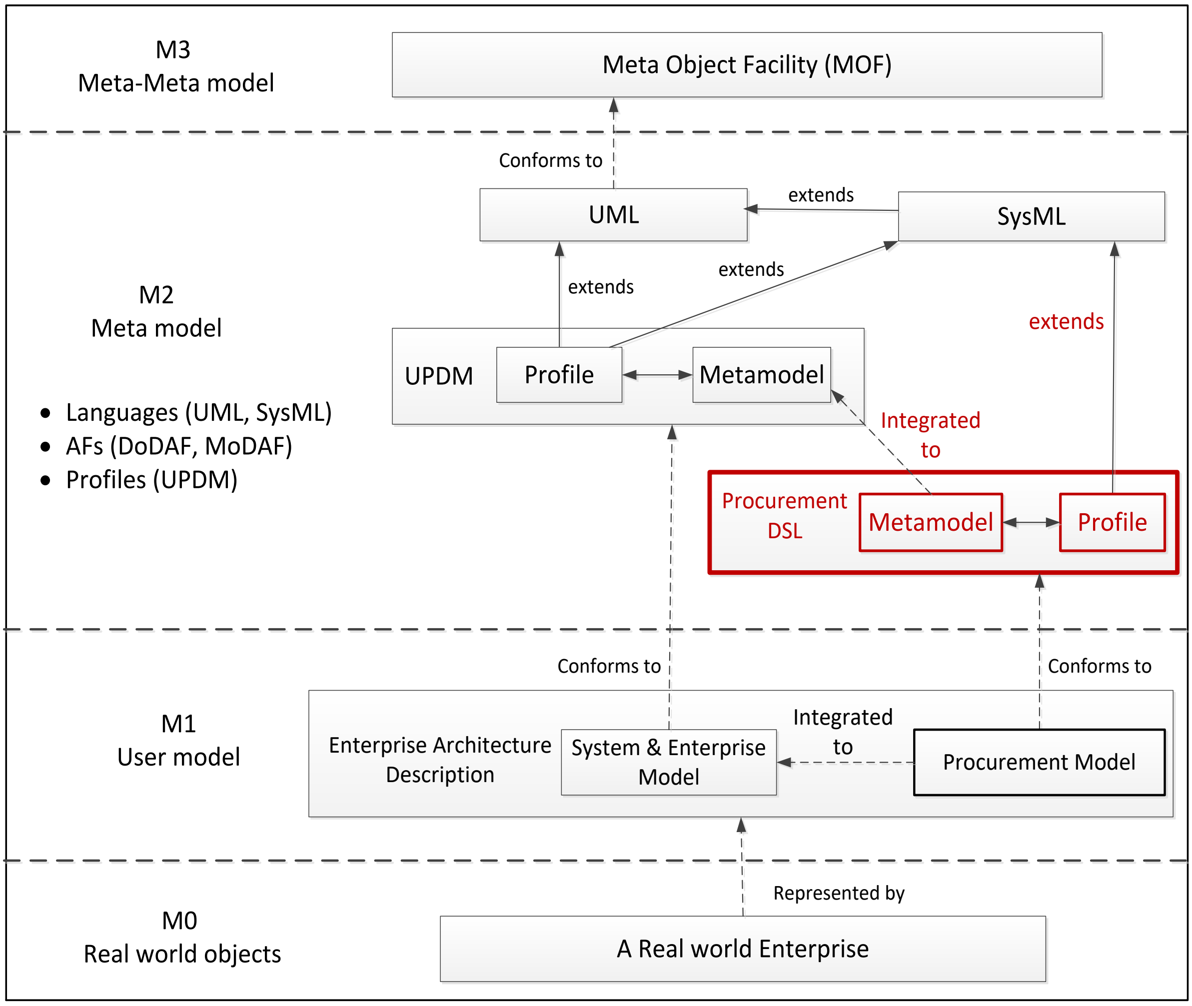

Figure 15: Putting the research deliverable into the context of existing literature

7. Limitations and final remarks

This study aims at facilitating the procurement of transport systems by applying modelling frameworks and enhancing them in support of procurement requirements. To better understand the transport procurement domain, six different procurement strategies are analysed. Fourteen salient requirements of procurement projects are thus identified. This set of requirements is used to identify modelling gaps in existing architecture frameworks. To illustrate this evaluation approach to the existing architecture frameworks, TRAK is applied on a real transport procurement project from the Transport for NSW to model the project. The effectiveness of TRAK in supporting the procurement stakeholders and their concerns is examined gaps are highlighted.

A limitation in our modelling case study was accessing the PPP procurement documents. The contract documents prepared by NSW government were fully available but the documents prepared by the private party (contractor) were not all publicly accessible. Analysing the government documents led us to identify the needs to modelling the costs and finances, but the actual cost and finance structure of the project was not available to us which limited our understanding of how exactly they need to be modelled. This limitation remains valid in collecting the information for the future research. To circumvent it, we will collect the procurement guidelines instead of real procurement documents in creating the procurement metamodel. Another limitation of this study was difficulties in accessing the project stakeholders to validate the quality of the case study models. Access to stakeholders was sought to ascertain their modelling needs in the information models. So, the generated models need to be discussed with the stakeholders to assure their concerns are considered in the modelling process.

The case study highlighted that nine of the procurement requirements are covered, but five others cannot be modelled by existing architecture frameworks. The covered requirements are mainly pertaining to the definition of the organization strategies, required operations, system functions and physical elements. However, the other main aspects such as the costs and finances of the project, quantitative value for money assessment and risk management are not supported but still identified by the metamodel elements. Whilst there are project management tools that can be used to support those, it is challenging to maintain the consistency between the generated models (or documents) and the architecture model. Without the use of a metamodel, the integrity of the information as a whole cannot be assured. A metamodel enables developing an integrated model of the whole projects which includes both the system aspects and procurement aspects from all the models. Indeed, a conclusion of this study is that to fill modelling gaps, a clear solution is to extend the metamodel of the architecture frameworks by identifying the procurement guidelines and their conceptual constructs.

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Appendix A. Details of the procurement strategies

A.1. Construct only (CO) (lump sum or fixed price)

In this commonly used form of contract, the government has full responsibility for the design and documentation and is expected to engage a design team to develop the design documentation that forms part of the tender for the works. The works are for the construction component only (Department of Infrastructure and Planning Queensland Australia, 2010). A contractor tenders a price for the works subject to adjustments provided for in the contract (e.g. if there are variations). Irrespective of the actual cost of the works, the contractor will be entitled to be paid the contract sum, as agreed between the parties prior to commencing the works. However, history has shown that in practice, if not properly planned and managed, the construct-only contract often exceeds the original contract sum (Government of Western Australia, 2016). For an AF to be used in this situation, these two areas need to be adequately covered:

- The AF thus needs to be able to articulate and/or reference the physical design of the system and the manner in which the components will be tested for acceptance.
- The AF needs to be able to capture the outcomes from any acceptance testing that is undertaken.

A.2. Design and construct (DC)

In this model, the acquiring organisation often develops a requirement specification, an operations concept, and a test concept. These are used to convey how the system is to be used in a variety of use cases, the requirements of the delivered system and how the system will be tested to meet them. For an AF to be used in this situation, these three areas need to be adequately covered:

- Upon delivery, the contractor has to provide supporting information on how the system is designed and operates.
- The contractor has to provide the outcomes of any tests performed during the design and build phases of the contract.
- A series of acceptance tests will then be performed to evaluate the system's ability to deliver the desired functions and performance.

A.3. Design, Construct and Maintain (DCM)

In this model, the Contractor has ongoing maintenance obligations in addition to design and construction. Lifecycle costs can be reduced if the Contractor takes into account ongoing maintenance obligations when designing and constructing the facility (Australia Department of Treasury and Finance, 2017). The features of this model are similar to the DC model but with the added transfer of lifecycle risk to the Contractor encouraging design efficiency and quality construction and finishes to reduce long term costs. Therefore, the AF needs to support the same representations as Design and Construct but in addition there is the need to add the maintenance aspects to be supported. This includes costing and maintenance plans for the system.

A.4. Public Private Partnership (PPP)

A public private partnership is a service contract between the public and private sectors. Typically, in a PPP delivery model, a concession makes the private sector operator (concessionaire) responsible for the full delivery of services in a specified area including operation, maintenance, collection, management, construction and rehabilitation of the system. Importantly, the operator becomes responsible for all capital investment and providing the assets. However, all assets are publicly owned even during the concession period. The public sector is responsible for establishing performance standards and ensuring that the concessionaire meets them. In essence, the public sector's role shifts from being the service provider to regulating the price and quality of service (Department of Infrastructure and Transport, 2012) (Infrastructure UK, 2013). One of the most common arguments used to promote PPPs is that the public sector will attain value for money by transferring the optimal amount of risk to the consortium. The level of risk can be changed by allocating responsibility for individual risks to those who are best able to manage them. As with everything else related to PPPs, the process of effective risk transfer is complex, costly and controversial (Aspin, 2004).

In order to show that PPPs are providing VFM governments will often release VFM reports that compare the costs of delivering the project publicly versus a PPP (Opara & Rouse, 2019). VFM reports compare the PPP's costs with a hypothetical model of how much the project would cost if it were pursued through public procurement. This model is called the public sector comparator. The PSC and VFM are the main fundamentals of bid evaluation (Committee of Public Accounts London, 2003). The one risk that the private sector cannot take on is statutory risk (Audit Commission, 2014). This means that no matter what, the public sector is ultimately responsible for the provision of the infrastructure and related services being provided by a PPP. So, even in the cases where the risk of operation and revenue generation is transferred to the private sector, the principal is responsible for providing affordable services, therefore having a mechanism for estimating the costs and revenues accurately is vital for the public sector (R.Vining & Boardman, 2006).

According to aforementioned the AF should be able to structure the performance standards and relate them to required services to officially determine the service quality. Also, the AF has to provide the means for defining project risks and their allocation to the bearing organization. Moreover, the financial modelling aspects including PSC and VFM and also modelling the costs and revenues of the project have to be supported by the AF.

A.5. Alliance Contracting (AC)

In the Alliance Contracting (AC) method, the government collaborates with one or more non-owner parties (e.g. a designer and constructor) to share the risks and responsibilities in delivering the construction phase of a project. All project delivery risks are shared by the alliance participants. The alliance contract and supporting structures promote a positive culture based on "no-fault, no blame" and unanimous decision-making, and requiring all participants to find "best for project" solutions. Because the behavioural culture is crucial to the success of alliancing, the selection of the right participants is paramount (Department of Infrastructure and Planning Queensland Australia, 2010). The non-owner parties are typically guaranteed reimbursement of their direct project costs and payment of corporate project overheads in an open-book arrangement. Targets for cost, schedule and other key parameters are developed jointly during the pre-construction phase. If actual delivery is better than the agreed targets, all parties share the reward ("gain share"). Conversely, if delivery does not meet agreed targets, the pre-agreed "pain share" formula applies (Government of Western Australia, 2016). The AC method caters for partnerships between the Government and Private Parties. In terms of its procurement requirements, AC can be considered as a specific form of Public Private Partnerships (since the basic concepts such as risk and revenue sharing are the same).

A.6. Construction management (CM)

In the construction management approach, the principal engages a construction manager (contractor or consultant). The principal manages the project scoping and engages the designer directly. The principal also engages the trade contractors directly, although these contracts are entered into by the construction manager as the principal's agent. The construction manager performs a managerial and coordination role (without delivery risk) and is generally paid a fee based on a percentage of the value of the works. This form of contract inherently has a hierarchical structure with relationships between the organizations in different hierarchy levels. Consequently, the organizational interconnectivity and responsibility of them has to be transparently defined and therefore should be supported by the AF.

A.7 Procurement Needs to be Supported by AFs

From the above examination of the various procurement models, fourteen elements have to be depicted to support the various procurement processes and scenarios. Table A.1 lists representational requirements that have to be depicted mapped against the acquisition strategy that requires the information. Both AC and PPP require most information to be depicted. This is not surprising as the partnership requires disclosure of almost all information between the various enterprises. Interestingly, the other five contract types require similar areas of information. Table 4 indicates how those requirements are addressed by the Viewpoints of discussed AFs.

Table A.1: Required depictions mapped to transport procurement strategies.

Depiction Requirement	*Procurement Strategy*					
	CO	DC	DCM	PPP	AC	CM
1. The goals, visions and strategies of the system acquirer	x	x	x	x	x	x
2. The user requirements (define the system at Operational Level)		x	x	x	x	
3. Specification of services to be provided by the system			x	x	x	
4. System Requirement Specifications	x	x	x	x	x	x
5. Design models (including functional and physical models)	x			x	x	x
6. Compliance with the regulatory standards (As required by: All acquisition strategies)	x	x	x	x	x	x
7. System verification and validation	x	x	x	x	x	x
8. Operation and Maintenance plans for the system			x	x	x	
9. The Project costs and finances	x	x	x	x	x	x
10. Project feasibility and viability	x	x	x	x	x	x
11. Quantitative bid evaluation which includes modelling the VFM and PSC				x	x	
12. The project risks and their allocation to the responsible organizations				x	x	
13. The inter connectivity of organizations involved in a procurement project				x	x	
14. Contract management and dispute resolution				x	x	

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Pascal Perez is a specialist of integrative infrastructure modelling used to explore complex interactions between social and technological components of infrastructure systems. He is a Fellow of the Modelling and Simulation Society of Australia and New Zealand (MSSANZ) and a member of the National Technical Committee of the Australian Urban Research Infrastructure Network (AURIN).

William Scott has been engaged in Systems Engineering since the 90s where he undertook research into enhancing SE tool capabilities using a combination of artificial intelligence techniques and natural language processing. Since he moved to University of Wollongong, he has been engaged in examining the application of MBSE to assist the acquisition and modelling of public transport system for TfNSW and Australian heavy rail.

Peter Campbell is an Honorary Research Professor at the University of Wollongong and recently retired from the Defence and Systems Institute at the University of South Australia where he was engaged in the use of MBSE in defence and infrastructure applications over the last 10 years. Previously he was the Director of the Decision and Information Sciences Division at Argonne National Laboratory which specialised in the development of decision support tools for application to complex behavioural problems for US defence agencies.