Selection and Application of MBSE Methodology and Tools to Understand and Bring Greater Transparency to the Contracting of Large Infrastructure Projects

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Selection and Application of MBSE Methodology and Tools to Understand and Bring Greater Transparency to the Contracting of Large Infrastructure Projects

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Abstract

The procurement of infrastructure systems is a complex domain of information which is very difficult to manage because the knowledge pieces are generated by isolated stakeholders who are also interdependent and affect each other. The interrelationship between stakeholder information which is generated as documents introduces a challenge to keep the domain knowledge consistent and integrated. This diffused area of knowledge threatens the transparency of contracts because there are opportunities to manipulate a piece of information for a particular stakeholder without changes that could be traced to the remaining information. There are document-based guidelines, toolkits, and frameworks published by government bodies and procurement agencies to regulate and manage this domain but they are only partially complete, they are difficult to follow and apply, they are specific to a sector or country, and cannot generate consistent domain knowledge. The model based approaches are based on the use of metamodels in the form of architecture frameworks (AF) and modelling languages which enable consistent and interconnected domain models to be generated. UPDM (Unified Profile for DoDAF and MoDAF) is an academically acceptable and widely used metamodel developed to model and procure complex systems. So, UPDM is analysed to assess whether it could model the system and its procurement domain. While UPDM is complete for modelling all levels of a system (high level operations, specific functions and physical parts), the procurement of the system is not fully covered by this metamodel. This is why the procurement guidelines and frameworks are used as the main sources of knowledge to create a Procurement Metamodel (PMM) for developing procurement artefacts in the form of consistent models. The PMM is integrated into UPDM so all the information about the ‘system’ and its ‘procurement’ will be developed as ‘one’ consistent model. A variety of metamodeling processes and validation techniques are reviewed and used to create a composite method for developing and validating the PMM. The knowledge sources (guidelines) are divided into development and validation sets. The tailored method contains a systematic process which uses a development set to develop the first version of PMM (1.0); this version is then compared against the validation set of guidelines to identify and add the missing concepts and generate version PMM 1.1. The validated metamodel is implemented as a UML/SysML profile which is called Procurement Modelling Language (PML). A metamodel quality assessment method is then used to benchmark the PML against the UML versions and assess its quality features, but to assess
the applicability of PML and demonstrate its capabilities, a series of real projects are collected and modelled by PML. The main contributions of this thesis can be summarised as 1) developing a method composed of the best practices for developing and validating modelling languages; 2) Transforming the partially complete sources with a variety of structures to a standardised, well-structured and complete source; 3) Transforming the document based procurement regulations to the model based and machine executable rules; 4) Allowing the contracts to be developed as a consistent model instead of a text based format; 5) Analysing and extending UPDM as the most recognised systems engineering metamodel.
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1. Chapter 1: Introduction

“If I had an hour to solve a problem and my life depended on the solution, I would spend the first 55 minutes determining the proper question to ask”

(Albert Einstein)

1.1 Infrastructure Procurement

Infrastructure refers to the fundamental facilities and systems serving a country, city, or area, including the services and facilities necessary for its economy to function [1]. It typically characterises technical structures such as transport systems (roads, bridges, tunnels, etc.), water supply, sewers, electrical grids, and telecommunications which can be defined as the physical components of interrelated systems which provide the commodities and services essential needed to enable, sustain, or enhance societal living conditions [2]. This is why infrastructure is inherently a set of interrelated systems with the characteristics of a system of systems (SoS) that aims to provide services to the public, and which ultimately makes the Government liable for their availability and quality.

The social and economic value of infrastructure cannot be underestimated because infrastructure specifically designed to improve the liveability of the urban environment, is fundamental to building communities, improving social wellbeing, and maintaining high standards of living into the future [3]. Well planned and managed investment in public infrastructure plays a vital role in supporting economic growth and providing the capacity to meet the increasing demand for services that accompanies strong population growth. Investment in roads, rail, and ports is essential for business development and to improve productivity and industry competitiveness. Infrastructure also underpins the delivery of community services such as education, health, law and order, public transport and housing [4].

The significant role that infrastructure systems have in economic growth and improvements in liveability makes their procurement a high priority concern for governments. While the successful delivery of key infrastructure is vital to state and federal governments, there are inherent risks associated with its delivery, such as the potential cost of failing to deliver any of the key project components (cost, quality, safety or schedule). It is therefore worthwhile
carrying out research aimed at creating appropriate tools to enhance the nation’s ability to deliver high-quality infrastructure projects.

The acquisition domain is a complex system of organisations with different cultures and concerns, and which carries out different activities. However, they all have a common goal: to develop a system that meets their requirements, addresses their interests, and brings them value. Figure 1-1 shows the main stakeholders and their dependencies in the acquisition domain, and while they all have interests in the infrastructure system, stakeholders concerns are not only about the Infrastructure System itself, they are also about the ‘acquisition of’ the system. System related concerns include the safety, security, performance and functionality of the system; while the procurement related concerns include project costs, project risks, responsibility of the contract sides, and project scheduling, etc.

Figure 1-1: Acquisition domain and the infrastructure system to be acquired

The term ‘Acquisition’ is often used by the defence sector to refer to obtaining the products and services required to address their identified needs. The US Defence Acquisition University (DAU) defines acquisition as “the conceptualization, initiation, design, development, test, contracting, production, deployment, Logistics Support (LS), modification, and disposal of systems, supplies, or services (including construction) to satisfy Department of Defense needs” [5]. DAU defines procurement as the act of buying goods and services for the government; therefore acquisition is a much wider concept than procurement because it covers the whole life cycle of acquired systems (see Figure 1-1). The non-defence
sectors tend to use the word ‘procurement’ to refer to buying systems and services, but due to the increasing complexity and interdependency of economic and social infrastructure systems, the concept of procurement is much more than buying goods and products because procurement systems are so tightly interrelated that integration has become a major issue. This means that considerations under procurement are becoming wider because they now cover various stages of a system’s life cycle, depending on their purpose.

1.2 Procurement Methods

Governments publish the rules of procurement in various documents, namely their strategies or methods, to regulate the procurement context. There are six common methods for procuring infrastructure: Construct Only (CO), Design and Construct (DC), Design, Construct and Maintain (DCM), Construction Management (CM), Public Private Partnership (PPP) and Alliance Contracting (AC).

In the Construct Only method, the government is responsible for design and documentation and is expected to engage a design team to develop design documentation that will form part of the tender for the works; these works are only for the construction component [6]. In the Design and Construct type, the acquiring organisation often develops a specification requirement and an operation and test concept to convey how the system is to be used in most instances, the requirements of the delivered system, and how the system will be tested to meet them [7]. In the Design, Construct, and Maintain model, a contractor has ongoing maintenance obligations in addition to design and construction. The lifecycle costs can be reduced if the Contractor considers the ongoing maintenance obligations when designing and constructing the facility [8]. In the Construction Management approach the principal engages a construction manager (contractor or consultant) to manage construction works on its behalf. The principal manages project scoping and engages a designer directly. Public Private Partnership (PPP) is a service contract between the public and private sectors, and typically in a PPP delivery model, a concession makes the private sector operator (concessionaire) responsible for delivering the services in a specified area, including the operation, maintenance, collection, management, construction, and rehabilitation of the system [4] [9]. In Alliance Contracting (AC) 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 the 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 require that all participants find “best for project” solutions [6].

The four procurement methods, CO, DC, DCM and CM are called conventional methods which are naturally adversarial, whereas PPP and AC are more recently issued methods and are naturally non-adversarial. In terms of distributing and sharing the risks and responsibilities between project stakeholders, AC can be considered as a subtype of PPP because PPP is a flexible form of contract which can represent non-adversarial procurement methods.

The adversarial and non-adversarial procurement methods are compared by Regan [10] from different aspects: ownership, the form of contract, contractor selection, the form of specifications, the incentive framework, risk management, and contractual relationships. The following is a description of four of the aspects which describe most of the key differences between the two types of contract.

1. Ownership:
   In a traditional contract, ownership in the form of residual control rights or the decision making prerogative is exercised by the principal [11]. Control is important in project procurement because it creates the incentive framework which applies to contract parties and effects the conduct of the acquirer and the contractor over the life of the contract [12]. Under a complete contract, the principal is liable for project risks except the ones specifically allocated to the builder. On the other hand, the PPP transfers decision-making (and ownership in some contracts) to the contractor, subject only to the principal sign-off of main aspects such as final design and service commissioning. The principal’s role is to monitor construction and manage the relationships with the private party during construction phase and following commissioning, and in duration of service delivery.

2. The form of contract:
   Conventional (traditional) contracts are normally in the form of short-term complete contracts that try to consider all the aspects which are relevant over the term of the contract [13]. The written provisions in such contracts are generally about dealing with disputes between the parties, change management, and mechanisms for decision making in conditions of uncertainty. A PPP is in the form of a bundle of contracts that grant the consortium with effective control of the asset and service delivery over the
term of the agreement, while a state agency monitors the service performance. The contract is incomplete but contains mechanisms to deal with changes over service intervals as long as a few decades (depending on the length of the contract). The contractor is only paid by state or the users for providing the services at the required standard.

3. **The form of specification:**

The requirements of an adversarial procurement are generally written as an input specification which defines the work to be performed, the materials to be used, and the method of construction. This approach assumes that the principal and its advisers have the best design, construction, and service delivery solutions. The recent evidence in the United Kingdom and Australia suggests that “non-traditional approaches to building design and innovation can deliver improved services including lower rates of recidivism, higher educational standards, and improved staff productivity” [14]. A PPP is an output specification introduced with the BOT (Build, Operate, and Transfer) procurement methods of the 1990s. In this method the principal’s service requirements are defined as the output specification and the ‘how to’ question are left to the contractor. In the other words, the design, construction, and lifecycle cost risks are allocated to the contractor or bidding consortium by writing the requirements as the output specification. The consortium takes the control of the project and has a strong incentive to deliver quality assets which minimise lifecycle costs. It also motivates the contractor to utilise new technology and innovative design and construction methods to lower the costs and ensure sustainable service delivery.

4. **The incentive framework:**

Traditional contracts mainly transfer the time and construction cost risks to the contractor. The principal is concerned with the delivery to specification, to minimise variations, and prevent the project’s time and cost overruns [15]. Under a fixed price contract with time constraints, the contractor will attempt to meet its obligations under the contract, avoid penalties for late delivery, manage and reduce costs. A risk that is involved with the construction contracts is that contractors may bid competitively based on a perceived ability to ‘cut corners’ or misinterpret the specification or scope of works to reduce costs and improve the margin during the length of the contract [16]. A PPP aligns the incentives that drive behaviours for the three fundamental
contract parties, the state agency as buyer of the service, the financier as investor, and the consortium as the main contractor company. Each of the mentioned parties has an interest in quality service delivery, the avoidance of long and costly disputes, and the resolution issues caused by unplanned changes. The potential tensions at the project level over obedience matters shows that PPPs may not be a fully collaborative contract. Nevertheless, the alignment of risk, incentive and objectives within a PPP arrangement suggest a cooperative approach that is a remarkable transition from conventional adversarial contracting to non-adversarial agreements [10].

In this thesis PPP is studied as the infrastructure procurement method for four reasons: 1) their successful history compared to traditional contracts; 2) the availability of complete and rich knowledge sources for this type of contract; 3) the flexibility of PPPs means they can be turned into many forms according to the project specifications; 4) their increasing popularity among government and private sectors.

The inefficiency of traditional public procurement approaches are pointed by the evidences built up over the past 30 years. Evidence from a number of OECD countries in the 1990s [14, 17] [18] [19] identified systemic faults with government’s use of traditional procurement approaches, including poor user satisfaction levels, time and cost overruns, and high transaction costs. Reports by the UK National Audit Office in 2003 and 2008 identified late delivery and over-budget performance in around 70% of public projects and in 2007 and 2008, comparison studies of traditional contracts and PPPs in Australia found that conventional adversarial contracts for major projects were systematically delivered late and over-budget compared with PPPs [18]. When PPPs are used for the right projects, the benefits in terms of value for money, accountability, and sustainability of public investment in infrastructure can be substantial. A selection of these studies is summarised in Table 1-1 and Table 1-2.

| Table 1-1: Comparing PPP and Conventional Procurement in the United Kingdom |
|---|---|---|---|
| Source | Comparison | Proportion of Projects Over Budget (%) | Proportion of Projects with Time Over-run (%) |
| | | PPP | Conventional | PPP | Conventional |
| National Audit Office, 2003 [20] | Contract award to final | 22% | 73% | 24% | 70% |
| National Audit Office, | Contract award to final | 35% | 46% | 31% | 37% |

Table 1-2: Comparing PPP and Conventional Procurement in Australia

<table>
<thead>
<tr>
<th>Source</th>
<th>Comparison</th>
<th>Average Over Budget (% of original cost estimate)</th>
<th>Average Time Overrun (% of original time estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PPP</td>
<td>Conventional</td>
</tr>
<tr>
<td>Infrastructure Partnerships Australia, 2007 [21]</td>
<td>Original approval to final</td>
<td>12%</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>Contract to final</td>
<td>1%</td>
<td>15%</td>
</tr>
<tr>
<td>Duffield review of PPP performance, 2008 [22]</td>
<td>Original announcement to final</td>
<td>24%</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>Budget approval to final</td>
<td>8%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Contract to final</td>
<td>4%</td>
<td>18%</td>
</tr>
</tbody>
</table>

In both developing and transition economies, non-adversarial contracting and private investment now account for a greater share of major infrastructure projects. According to the Australian Department of Finance [23] “PPPs are used most frequently for major asset and infrastructure procurements”. The main cause of increased use of PPP is constraints on public sector borrowings and greater dependency on private foreign investment and expertise to fast-track improved economic and social infrastructure to boost economic and social development [24]. A further motivation for governments to adopt PPP is the greater complexity of infrastructure services, the pursuit of innovative design and construction outcomes, and the growing recognition of the importance of risk and life cycle costing to long-term investment in infrastructure services. Therefore, the infrastructure departments of different countries, which are the main sources of knowledge in this study, provide more complete, richer, and more consistent information about this type of contract compared to other contract types. Since conducting systematic research requires accessing rich and consistent information, the availability of PPP knowledge sources is the second reason for choosing this procurement method.

The third reason for picking PPP is the number of possible forms of this contract. PPP is the most flexible type of contract because it can allocate responsibilities to both sides of a contract in many ways, and therefore, developing a framework based on PPP’s can be used to handle the complexities of many different types of contracts. This means that studying PPPs
includes studying a large variety of relationships between procurements main roles and responsibilities, regardless of which side of the contract responsibility is assigned.

1.3 PPP challenges and existing approaches

The inherent collaborative features of PPP contracting make it a complex domain with a variety of entangled and interconnected organisations. Since the contracting process is complex, governments publish PPP guidelines and frameworks to regulate the contracts and facilitate contracting activities. These guidelines consist of the contracting process, typical roles of the organisations involved, instructions on how to develop the contract materials, and the format of the documents that they generate and exchange. Despite the completeness and expressiveness of the procurement guideline documents, which are written in natural language, there are still many problems regarding the understanding, interpreting, and consistent application of these rules. Moreover, the procurement processes involve large amounts of documents that must be prepared by the entire contract parties i.e. public sector, private sector, lenders, equity holders, regulators and sub-contractors.

Generating these documents and keeping them consistent during the refinements and modifications that occur during any bidding activity and the following contract negotiations is very challenging, and although the guidelines suggest standard formats, the documents generated by both sides of the contract are often far from being in a unified and standard structure. These issues introduce ambiguities and inconsistencies in the procurement stages, and make the procurement transactions long and costly due to the skills and expertise needed for documentation. Local governments often lack the staff needed to plan, negotiate, and monitor a contract suitable for local circumstances and must spend significant resources acquiring the expertise and advice required. A 2007 report from the UK National Audit Office [25] found that the average cost of external advice in procuring Private Finance Initiative deals was just over £3 million per project.

The other problem with PP is the limited transparency and accuracy in some of the processes conducted by government agencies which directly affects the selection of a successful bidder, such as risk calculation and assessing the value for money of the project. Surveys of PPPs in the UK [26] [27] and Canada [28] suggest that the methodologies used to calculate risks and the monetary value associated with any transfer of risk is always complex, subjective, and often less than transparent.
The KPMG studies on the Australian PPP market [29] find that best practice in Australia does not always apply consistently across all jurisdictions or across all projects within a jurisdiction. This result also indicates that domestic and potential international participants in the Australian PPP market have cited the overall complexity of the PPP procurement processes and the lack of understanding of PPPs within the context of the Australian market as key barriers to entry.

The awareness of these problems suggests that the PPP procurement context lacks a consistent method for generating information and a standard structure for sharing knowledge among the stakeholders which leads to a common understanding of the shared information.

Many approaches have been used to tackle these problems; one group of approaches are the document based frameworks, best practices and reference guides published by academia [30, 31] and expert PPP agencies [32]. Another approach are toolkits, such as The European PPP Expertise Centre (EPEC) Toolkit [33], Public Private Infrastructure Advisory Facility (PPIAF) Toolkit [34], World Bank and AusAID Toolkit developed for the Indian Ministry of Finance [35], and the Asian Development Bank Toolkits [36, 37]. These toolkits are more structured documents held in web pages and excel files, and which are designed to help calculate the financial aspects of a project. Although these approaches are helpful via summarising and simplifying the regulations, they cannot assure that consistent and complete procurement documents will be generated.

The third approach may be called model driven because it is based on the application of metamodels and model based frameworks (also known as Architecture Frameworks). Domain metamodels are a standard definition of the domain concepts and therefore bring a common understanding of shared information to stakeholders. LOTED2 [38] is a metamodel which supports the modelling of European procurement notices and describes the data extracted from the TED (Tenders Electronic Daily) system [39]; it also aims to represent legal concepts related to the public procurement domain. Examples of using metamodels for procurement are the development of frameworks by the US and the UK departments of defense to acquire complex systems; they are known as DoDAF (Department of Defense Architecture Framework) and MoDAF (Ministry of Defence Architecture Framework). These AFs provide a standardised knowledge structure for sharing information, while the metamodels generate consistent and integrated models of the ‘system’ and the ‘procurement project’ defined to acquire the system (these two domains are shown in Figure 1-1).
This study analyses the application of model based approaches in the context of systems engineering (Model Based Systems Engineering) to understand how they can be of use in the infrastructure procurement domain, and how they can be used specifically to develop a standard solution to overcome the challenges of PPP procurement. 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” [40]. MBSE facilitates systems engineering activities traditionally carried out using a document-based approach, and result in enhanced communications. [41]. According to the studies on MBSE since 2006 [41] [42] [43] [44] [45] [46], practicing MBSE involves six fundamentals: 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 establishing a systems engineering approach; so the first step in practicing MBSE is to identify the fundamental processes of the domain of study. The systems engineering process defines ‘what’ activities are performed, but does not generally give details on ‘how’ they are performed. A Systems Engineering (SE) Method describes how activities are carried out in terms of the types of artefacts produced and how they are developed. Architecture Frameworks identify and define the artefacts needed to carry out those activities; these artefacts are created as related concepts (metamodel). While AFs identify ‘what’ is to be modelled, Architecture Description Languages or modelling languages indicate ‘how’ those artefacts should be modelled. Figure 1-2 shows the translation of ‘Whats’ and ‘Hows’ to each other via these MBSE fundamentals. Model and data interchange standards support the model and the exchange of data between tools. Modelling tools are designed and implemented to comply with the rules of one or more modelling languages to enable practitioners to construct well-formed models in those languages.

![Figure 1-2: The MBSE fundamentals and their relationships](image-url)

The focus of this research is the analysis and extension of Architecture Frameworks which contain the constituent concepts of a domain (in this research infrastructure the procurement
domain), and the Architecture Description Languages, which is how these concepts are expressed.

1.4 Research Aim and Objectives:

Every project is different and has its own unique issues and requirements, which means there is always a need to tailor the contractual documentation to address specific project requirements. Furthermore, the commercial dynamics of a social infrastructure PPP with a government sourced revenue stream are quite different from those of a user pays PPP project which requires (or allows) different approaches to the allocation of certain risks. This is particularly pertinent to the interface (and risk allocation therefore required) between services provided by the private sector and core services retained by the State [47].

The non-standard nature of contractual documentation for most PPP projects is one of the factors which contribute to the higher costs of bidding for them because lower bid costs will lead to greater willingness to participate in bids and hence more competition for projects, all of which leads to better value for money for government. Therefore, the desirable aim of this study is standardising and facilitating contractual interactions; the benefits of standardisation are as follows:

- Facilitating the generation and modification of documents
- Assuring the procurement information during refinement and changes is consistent
- Assuring transparent application of the rules and guidelines
- Facilitating the integration of procurement phases and integrating the activities of procurement stakeholders

The management approaches for managing the PPP challenges were discussed in section 1.3; it was also discussed that the model methods are the latest generation of approaches which have been practiced by the world leading organizations. So, this research hypothesises that MBSE methodologies can be employed to develop a customized metamodel and a modelling language for PPPs which can lead to more successful PPP projects by providing a common understanding of the project to the stakeholders and keeping their interrelated information in a consistent and integrated database (that is known as the model repository). The PPP success should be measured through the project being on budget, on schedule and value for money. Testing the hypothesis against these criteria by practical application of the metamodel on the real PPP projects and measuring the effects of the language on the success of the PPPs in
beyond this research. So this hypothesis is assessed by validating the metamodel and the modelling language in 3 different methods: 1) comparing the metamodel against the existing PPP frameworks that are not used in development of the metamodel (section 4.2); 2) quantitative comparison of the modelling language to UML as the most widely used modelling language (section 5.2); 3) application of the modelling language on the previously conducted PPP projects to assess the applicability and practicality of the modelling language (Chapter 6).

In order to achieve the aims of this study, the following objectives are defined:

1. To study how MBSE methods can be applied during procurement and whether they will meet the needs of the infrastructure procurement domain.

2. To study the different systematic approaches of metamodelling and language design to extend the current MBSE methods and improve their ability to support infrastructure procurement.

3. To review and gather the procurement guidelines and standards and create a complete source of knowledge and then create a complete and well-structured knowledge source.

4. To design, implement, and validate a procurement metamodel using the gathered knowledge,

5. To develop a modelling language based on the created metamodel.

6. To apply and validate the language using real world case studies to assess its applicability and usefulness.

1.5 Organisation of the thesis

This thesis has 7 chapters, so to facilitate accessing the contents, a brief description of each chapter is provided.

Chapter 1 gives an overview of the research by describing the infrastructure systems and their procurement methods. The challenges of this infrastructure procurement are discussed to define the research problem which leads to a definition of the aims and objectives of the research.
Chapter 2 reviews the relevant published research work; it begins by describing the procurement problems named in chapter 1. The current procurement management methods are then reviewed and UPDM is selected as the best practice to focus on; UPDM is then analysed to identify the research gap, followed by stating the research goal. Finally, the metamodel development and evaluation techniques are reviewed to ensure that best practices are used in this study.

Chapter 3 describes the design science cycles and how the phases of this research fit into them. A metamodel development and validation method is tailored using a combination of best practices; the steps of which are also explained in this chapter.

Chapter 4 uses the tailored method to develop the first version of a procurement metamodel (PMM 1.0). The second part of this chapter uses a validation method (comparing the metamodel against other guidelines) to identify and add the missing concepts to the metamodel and create PMM 1.1.

Chapter 5 uses PMM 1.1 as an abstract syntax and implements it as a UML/SysML profile (concrete syntax). The objective here is the Procurement Modelling Language (PML). In the second part a metamodel assessment method is used to benchmark the PML against the UML versions.

Chapter 6 applies the PML to some real cases where six real contracts from different sectors and different countries are collected and modelled by the PML.

Chapter 7 summarises the research and highlights the research contributions, and follows with discussing the research limitations, future works, and the possibilities for extending this research.
2. Chapter 2: Literature Review

“Research is to see what everybody else has seen, and to think what nobody else has thought”

(Albert Szent-Gyorgyi)

2.1 PPP Procurement problems

Chapter 1 describes different procurement methods, compares the adversarial and non-adversarial methods, and discusses why this study focuses on the PPP method. Although governments are increasingly attracted to PPPs as the main option for procuring infrastructure, there are barriers and issues which make the entry to a PPP challenging. The main problems which motivated us to propose a solution are discussed below, but these problems are not solely related to PPPs, they are also associated with procurement processes in other contract types because PPPs are more complex in terms of structure and interdependency between the stakeholders, as well as the complexities of other types of contracts. Consequently, the proposed solutions can generally be used in almost any procurement method.

2.1.1 Complexity, Cost, and Length of PPP procurement processes

Good procurement is believed to be the key to achieving value for money because competition among bidders during the procurement stage will lead to an ideal mix of price, innovation, and quality and risk transfer [48]. However, the complex processes that preface PPPs are a nagging problem that deters potential bidders and compromises competition. The complexity of the process is rooted in complex decision making and documentation that make procurement process costly and long.

According to a framework developed by Alberta Infrastructure and Transportation [49] the procurement will take anywhere from one year to sixty-eight weeks to complete, assuming that nothing goes wrong. A 2004 study from the United Kingdom [50] examined 32 cases and found procurement in 98 per cent of them took anywhere from 11 to 166 per cent longer than expected, while cost overruns were 25 to 200 per cent more than the initial expectations. The main reasons for cost overruns were the procurement related hidden costs associated with preparing documents and other advisory consultations.
Local governments often lack the staff needed to plan, negotiate, and monitor a contract suited to local circumstances and are forced to spend significant resources acquiring the necessary expertise and advice. In Cornwall, Ontario, the local paper [51] reported mounting costs associated with procuring a recreation centre as a PPP; the costs included $95,000 to Ernst & Young for related services, including preparing documents and exploring the possibility of a PPP, as well as $125,000 to a Toronto law firm for helping to prepare the agreements and documents needed in a PPP deal. In Halifax the consultant fees associated with preparing an RFP for a four-pad arena came to $128,640 [52].

2.1.2 The risk calculation is complex, subjective, and less than transparent

Transparency is a key concern in the procurement process. In May 2008 Business in Vancouver conducted a survey of business leaders in British Columbia [53]; most respondents are in favour of PPPs, except when it came to the question of transparency where 55% said PPPs are not transparent about procurement, funding, and operation.

A common argument used to promote PPPs is that the public sector will receive value for money by transferring the optimum amount of risk to the consortium. According to Thomas Ross, an expert on PPPs, [54] risk transfer in and of itself is not a good reason to do a PPP; he writes that the goal of a PPP should be to transfer risk to the party best able to manage it at the minimal cost, but as with everything else related to PPPs, the process of effective risk transfer is complex, costly and controversial. In the case of using a PPP contract for the design and construction of schools in the United Kingdom [26, 27], the Accounts Commission had serious reservations about the estimates for risk transfer being produced; they found the process used to determine the probability and value of risk to be entirely subjective. Canadian academic Daniel Cohn writes, “The methodologies employed in the calculation of risks and the monetary value associated with any transfer of risk are always complex, subjective, and often less than transparent; they are also sometimes proprietary secrets” [28].

Ronald Aspin [55] points out that “when it comes to engaging in public-private partnerships it would appear that local government is the most vulnerable to exploitation by a better skilled and more experienced private sector in terms of recognizing and allocating risk.” He also writes, “it is the very fact of their small size and finances that makes them (local government) vulnerable as they do not have the capacity to carry ‘in-house’ the sort of specialist expertise necessary in the lead up to a partnership formation, and the cost of
contracting these expert advisors can be prohibitive”. Moreover, it is essential that larger Federal or State governments retain the necessary expertise for preparing documents because having a standard, uniform and accurate framework for calculating and allocating risk is crucial for having a successful contract.

2.1.3 Lack of transparency and accuracy in PSC and VFM

In order to justify PPPs to the public, governments often produce ‘value for money’ reports, or assessments, which show how the costs of the PPP compare to the costs of a publicly procured alternative. VFM implies that PPPs are a better use of taxpayer dollars if the overall benefits to the public are greater than the benefits of conventional public procurement. VFM can be defined as “a broad term that captures both quantitative factors, such as costs, and qualitative factors, such as service quality and protection of public interest” [56], so to show that PPPs are providing VFM, governments often release VFM reports that compare the costs of delivering the project publicly versus a PPP. VFM reports compare the cost of PPP’s 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.

Stuart Murray has examined a number of VFM reports and noted their problems, and in terms of timing Murray notes that VFM reports are usually released after PPPs have ‘passed the point of no return’ when contracts have been signed [57]; this late release prevents public scrutiny before PPP contracts are signed. Similarly, in Ontario, initial VFM assessments are withheld from the public [58], a practice which contradicts recommendations made in other public documents. For example, a recent discussion paper on PPPs in municipal water services written for the Government of Canada’s Policy Research Initiative recommends that the community should be involved in the procurement process from the beginning and that the contracts, let alone the reports explaining the contracts, should be made public before they are signed [59].

Public sector comparators (PSCs) are a key to making the case for PPPs because they are the benchmark against which PPPs are measured. The Canadian government stresses that PSCs should be developed “early on in the planning process at the highest level” because of their importance in determining whether a PPP actually produces value for money [60]. It is therefore very important to have a transparent and standard framework for calculating the VFM and PSC to be used for comparing to the public sector. The problems with PSCs can also be found in the United Kingdom; the UK House of Commons Public Accounts
Committee stated that: “The accuracy of public sector comparators is limited. They are prone to error because of the complexity of the financial modelling that is often used” [61].

2.1.4 Misestimating the costs and revenue

The private sector cannot take on statutory risk [62], which that regardless of the circumstances, the public sector is ultimately responsible for providing the infrastructure and related services being provided by a PPP. Experience has shown that when the private sector is unable to manage risk (such as financial or user risk), the public sector has been forced to step in and bail it out [63], so even in cases where the risk of operation and revenue generation is transferred to the private sector, the principal is responsible for providing affordable services. This means that the public sector must have a mechanism to accurately estimate the costs and revenues.

In 2007 the Ottawa Citizen obtained copies of a confidential report detailing the failures of the Bell Sensplex and the Ray Friel Centre [64] projects. With the Ray Friel Complex, the report said that the company responsible for the centre had overestimated its revenues and underestimated its operating costs, so since the city had few options available, the report recommended the city take over the facility and the company’s $12-million debt [65].

A similar story happened in Cranbrook, British Columbia where a PPP to build a new recreation complex had to be terminated when the partner underestimated its operating costs and overestimated its revenues. The PPP experiment there left the city on the hook for millions and the highest debt level of any BC municipality [66].

2.1.5 Difficulties in understanding and applying PPP regulations

Infrastructure Australia engaged KPMG to help identify and find practical solutions to the most significant barriers to competition and efficiency in the procurement of PPPs. KPMG published a report in May 2010 [29] in which they expressed the results of their analysis. According to this report “almost all Participants indicated a high level of confidence in the Australian PPP process. However, a majority of Participants noted that best practices in Australia do not always apply consistently across all jurisdictions or across all projects within a jurisdiction”.

The efficiency of the procurement process can significantly impact the level of transaction costs to Government and the bid costs incurred by market participants. In another part of the report KPMG writes “Although Participants are happy with Australian PPP processes, the
most important issues that Participants raised are in relation to inefficiencies in the procurement process” including:

- excessive requirements for information and documentation (almost all)
- inconsistencies in and reduced quality of tender processes and documentation (a majority)

The key factors cited by Participants as driving these inefficiencies are:

- the skill and expertise of the Government team managing the procurement process (almost all)
- the Government’s level of commitment to the project and the PPP procurement model (a majority).

As mentioned before, PPP procurement processes are complex, and while some of this complexity is necessary to deliver the outcomes that Governments desire from PPP projects, these projects require significant upfront investment by new domestic entrants in recruiting staff with the requisite skills and knowledge. For experienced international participants, there are also significant set up costs associated with the development of an Australian capability. The KPMG study also indicates that “both domestic and international potential participants in the Australian PPP market have cited the overall complexity of PPP procurement processes and the lack of understanding of PPPs within the context of the Australian market as key barriers to entry” [29].

To improve the PPP processes “Participants suggest that Governments could improve the process from the perspective of minimising multiple requests for similar information throughout the documentation as well as the development of a central repository for generic information” [29]. These issues show that a standard and unique framework is needed to ensure consistent processes by translating the rules to an “easier to understand and apply” regulating mechanism that will feature a common and more transparent understanding of the rules and thus eliminate the barriers to entry to PPPs.

2.2 Importance of Transparency and Accountability

The main issues and challenges of PPPs that should be resolved to have successful procurement are discussed above, of which transparency in the main processes such as risk management and VFM assessment is a critical success factor. In this section, the importance
of transparency and accountability is explained as discussed in Commonwealth Procurement Guidelines [67] and National PPP Guidelines [68].

Accountability and transparency encourage the efficient, effective and ethical use of national and state resources; therefore an agency and its officials must ensure that any procurement process is open and transparent and the decisions are justified, while agencies must have procedures to ensure that procurement processes are conducted soundly and that procurement related actions are documented, defensible, and substantiated in accordance with legislation and government policy [67]. Accountability means that officials are responsible for the actions and decisions they take in relation to procurement, and for the resulting outcomes. Transparency provides assurance that procurement processes undertaken by agencies are appropriate and that policy and legislative obligations are being met. Transparency involves agencies taking steps to support appropriate scrutiny of their procurement activity, indeed the fundamental elements of accountability and transparency are policy and legislative obligations, documentation and disclosure. These are outlined below.

2.2.1 Complying with policy and legislative obligations (probity)

Officials undertaking procurement must comply with relevant general government policies and legislative requirements [67]. Probity is an important issue for government because they are custodians of the community’s assets, and since PPP transactions can involve a lengthy and complex tender process, good process and probity are consistent with achieving value for money in commercial engagements. Probity management is an integral part of the process, not a separate obligation [68]. Key aspects of probity are:

- ensuring conformity to the process;
- ensuring the principles of openness, fairness, and transparency are maintained throughout the process.

The procurement metamodel developed in this research should make compliance with the rules easier for the practitioners, as well as facilitating contract development.

2.2.2 Documentation

Documentation is critical to accountability and transparency because it provides a record of procurement activities and how they have been conducted, and facilitates scrutiny of these activities [67]. Agencies must maintain the appropriate mix and level of documentation for each procurement project, but this level depends on the nature and risk profile of the
procurement being undertaken. Agencies must also ensure there is enough documentation to provide an understanding of the reasons for procurement, the process that was followed, and all the relevant decisions. A consistent PPP framework (Procurement metamodel) can facilitate and improve the accuracy of documentation and maintain the interconnectivity of documents to assure their consistency. This means there are huge interdependencies between all the stakeholders and their documents, and they can be a barrier to transparency. The metamodel developed in this research keeps the linkages between all the documents to ensure that changes in any document can be traced and distributed to the remaining related documents.

2.2.3 Disclosure

Disclosure is the mechanism by which agencies make their procurement activities visible and transparent. The broad aim of disclosure is to provide confidence in the processes that an agency intends to undertake, or has undertaken, and reassurance that the Chief Executive is promoting the efficient, effective and ethical use of resources.

2.3 Current procurement management approaches

A variety of approaches are used to tackle the procurement problems. These approaches are reviewed here.

2.3.1 Document based approaches

2.3.1.1 PPP management tools (Toolkits)

Most PPP management tools are developed as toolkits; the following is a list of PPP toolkits:

EPEC PPP Guide [33]:

The European PPP Expertise Centre (EPEC) has published several versions of its Guide to Guidance in PDF format [69] as per the request of European Investment Bank. This Guide to Guidance is principally aimed at public procuring authorities who are considering the use of public-private partnership (PPP) arrangements. EPEC then decided to turn the Guide to Guidance into a web tool rebranded as the EPEC PPP Guide which aims to give users easy access to regularly updated PPP guidance. Despite the toolkit being implemented as a web based tool, it is still in document format.

PPIAF PPP toolkit [34]:
The Toolkit for Public-Private Partnerships in Roads and Highways provides guidance for public sector authorities in the definition of strategy and policy for PPP, and the definition of PPP projects and stages for their preparation. This toolkit is created by the Public Private Infrastructure Advisory Facility (PPIAF) in conjunction with The World Bank. The toolkit is published in PDF format, the diagrams and figures are in JPEG format, and the financial models are developed in excel files. These types of files are mentioned deliberately to stress that the toolkit is developed in document format, not in integrated and unified models.

**PPP in India Toolkit [35]:**

The Public Private Infrastructure Advisory Facility (PPIAF), and the World Bank and AusAID provided funding to the Department of Economic Affairs, Ministry of Finance, the government of India (DEA) to prepare a Toolkit for improving PPP decision-Making Processes. This toolkit provides tools, methodologies, and processes to assist the governments/agencies to strengthen decision-making at all key stages of the PPP project cycle; it covers highways, water and sanitation, ports, solid waste management and urban transport sectors. A PPP financial model and a VFM indicator have been developed as excel files.

**Asian Development Bank PPP Toolkits:**

ADB has published 2 toolkits and a handbook to facilitate the management of infrastructure procurement through PPPs. Two toolkits are designed for PPP in urban bus transport [36] and urban water supply [37] for the state of Maharashtra, India. This PPP handbook [70] provides an overview of the role, design, structure, and execution of PPPs for infrastructure development. With inputs from policy and transaction specialists, this handbook also addresses a range of matters associated with PPPs, from policy considerations to implementation issues.

2.3.1.2 **PPP Frameworks and best practices**

The Asian Development Bank has published the best practices for promoting private sector investment in infrastructure in five sectors: Water supply [32], ports [71], Power [72], Airports and Air traffic control [73], Roads [74]. All these documents are published in Pdf format.

Ester Cheung in his PhD thesis [30] ‘Developing a Best Practice Framework for Implementing Public Private Partnerships (PPP) in Hong Kong’ has developed a framework
in a table format to serve as a guideline when implementing PPPs. Research by Ting LIU et al. [31] developed a PPP framework that was published in their paper ‘PPP Framework for Public Rental Housing Projects in China’. The third academic research on PPP frameworks is published by La Anh Tuan as ‘Best practice framework for implementing PPP infrastructure projects: Vietnam perspective’ [75].

2.3.1.3 Government regulations, policy and guidelines

Since PPPs are very complex and challenging, governments publish separate regulations, policies and guidelines that are usually used as frameworks. A full list of PPP guidelines published by different countries is published by the World bank [76]. The United Kingdom and Australia have provided the most complete and detailed set of guidelines; the Australian PPP regulations are published by the Department of Infrastructure [77] and the Department of Finance [78]. The UK has published its PPP regulations by UK Infrastructure, which is part of HM Treasury [79]. Other examples of these frameworks are: PPP legal framework in Poland [80], PPP Framework in Philippines [81], Policy Framework for Public Private Partnership (PPP) in Ireland [82] and ASEAN (Association of Southeast Asian Nations) Principles for PPP Frameworks [83].

Asian Development Bank (ADB), Inter-American Development Bank (IDB), World Bank Group and Public-Private Infrastructure Advisory Facility (PPIAF) have published international guidelines for PPPs in the ‘Public-Private Partnerships Reference Guide: Version 2.0’ [84] which is a valuable source of information used in this research. This reference guide presents a global overview of the diversity of approaches and experiences used to implement public-private partnerships (PPPs), by providing an entry point to the substantial body of knowledge on PPPs built up by practitioners in governments, the private sector, international institutions, and in academia.

2.3.2 Model based Approaches

2.3.2.1 Public Contract metamodels

TED (Tenders Electronic Daily) is an online version of the 'Supplement to the Official Journal of the EU, dedicated to European public procurement. TED provides free access to business opportunities, and it is updated 5 times a week with some 1,500 public procurement notices from the European Union, the European Economic Area and beyond [39].
LOD2 (Linked Open Data v2) is a large-scale Integrated Project co-funded by the European Commission within the FP7 (Seventh Framework Programme) Information and Communication Technologies Work Program; the overall aim is to create knowledge out of interlinked data and develop tools and methodologies for exposing and managing very large amounts of structured information on the Data Web, and to test and bootstrap a network of high-quality domains.

LOTED2 is a legal ontology (metamodel) which supports the modelling of European procurement notices and describes the data extracted from the TED system. Since LOTED2 is a legal metamodel, it aims to represent the legal concepts related to the public procurement domain. Such an expressive modelling of the domain enables connections with other domains such as business to be discovered, as well as integration with other relevant metamodels and e-commerce scenarios [38]. At the heart of LOTED2 is a Public Contract Ontology to capture the contractual concepts; this ontology is described as one of the project deliverables [85].

### 2.3.2.2 Acquisition architecture frameworks

The defence industry deals with the acquisition of large systems with complex integration and interoperability challenges, so it has pushed them to develop Acquisition Architecture Frameworks to facilitate the design, procurement, and the building and testing of such systems. These frameworks are metamodels that are developed to model the architecture (of an enterprise or SoS). DoDAF (Department of Defense Architecture Framework) and MoDAF (Ministry of Defence Architecture Framework) are two widely used AFs. The ‘Architecture’, ’Architecture Framework’ and ‘Architecture Modelling’ are described in details in later sections.

### 2.3.3 US DoD & NASA Acquisition models

U.S. Government departments and agencies such as the U.S. Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) are responsible for managing billions of tax payer dollars annually in the development and acquisition of large-scale, complex systems. Consequently, these agencies must follow rigid acquisition guidelines to insure that they are good stewards of U.S. tax payer dollars, and that there is accountability for investment in such large-scale and potentially very costly programs[42]. This is why the methods and approaches developed by these agencies are followed as the best practices of acquisition in this research.
US DoD best practices for acquisition are rooted in DoD policy directives and instructions, namely, DoD Directive (DoDD) 5000.1 *The Defense Acquisition System* [86] and DoD Instruction (DoDI) 5000.2 *Operation of the Defense Acquisition System* [87]. DoD’s revised acquisition policy includes a lifecycle framework that is depicted in Figure 2-1.

![Figure 2-1: US DoD Lifecycle Framework](image)

NASA best practices for acquisition are rooted in NASA policy directives and requirements; specifically, NASA Policy Directive (NPD) 7120.4 *Program/Project Management* and NASA Policy Requirement (NPR) 7120.5 NASA *Program and Project Management Processes and Requirements* [88] [89]. Similar to the US DoD acquisition lifecycle model, the NASA lifecycle model has a set of key lifecycle phases as well as decision milestones and gate reviews, as shown in Figure 2-2.

![Figure 2-2: NASA Project Lifecycle](image)

The US DoD and NASA acquisition lifecycle models captured here can be considered metamodels on which project- or domain specific plans are built. The fundamental theory on which these metamodels are based is Systems Engineering (SE), a multidisciplinary approach
to develop balanced system solutions in response to diverse stakeholder needs. Systems engineering includes the application of management and technical processes to achieve this balance and mitigate risks that can impact the success of the project [41]. SE is explained in more details as one of the theoretical foundations of this research in section 2.4.1: Systems Engineering.

It must be emphasised that acquisition program reviews usually rely on paper documents because that was state-of-the-art when government acquisition lifecycle models commenced [90]. This approach generates textual specifications and design documents in hard-copy or electronic file format that are then exchanged between customers, users, developers, and testers. This approach is known as Document Based Systems Engineering (DBSE); it does have the inherent problems of document centric approaches such as difficulties in keeping the documents generated at each life cycle stage consistent and complete, as well as hassles in tracing the effect of changes within the domain sections. The U.S. Department of Defense therefore began to use model based approaches, so the C4ISR framework [91] was introduced in 1996 to provide a framework for architecting information systems for the DoD. The Department of Defense Architecture Framework (DoDAF) [92] evolved from the C4ISR framework to support architecting an SoS for the defence industry by defining its operational, system, and technical views. Model based approaches, including the architecture frameworks, are based on developing an architectural model of the SoS (or Enterprise) which is standardised by IEEE 1471-2000. The IEEE 1471-2000 standard was approved in 2000 as a “Recommended Practice for Architectural Description of Software-Intensive Systems” [93]. This standard is explained in more detail as the second fundamental theory of this research in section 2.4.2, Model Driven Architecture.

2.4 Theoretical foundations

The best practices of the SoS acquisition methods developed by U.S. Department of Defence and NASA are discussed in the previous section. Since the foundation of those methods are Systems Engineering, they are explained here as a foundation of this research. Moreover, the transition from a document based to a model based approach is based on IEEE1471/ISO42010, so it is discussed here as the second theoretical foundation.

2.4.1 Systems Engineering

2.4.1.1 Fundamental Processes and Standards
A systems engineering (SE) process model defines the primary activities that must be performed to implement systems engineering. SE processes are related to the phases in an acquisition lifecycle model which usually begins at an early stage in the system lifecycle, typically at the very beginning of a project [42]. A variety of SE process standards have been proposed by different international standards bodies, but most SE process standards in use today have evolved from the early days of DoD-MIL-STD 499 [94].

The ANSI/EIA 632 Processes for Engineering a System standard [95] and the IEEE 1220-1998 Standard for Application and Management of the Systems Engineering Process [96] were sources into the creation of ISO/IEC 15288:2002 Systems Engineering—System Life Cycle Processes [97]. A graphical depiction of the three full standards that illustrate their primary scope is shown in Figure 2-3.

![Figure 2-3: Breadth and Depth of Leading SE Process Standards](image)

NASA distinguishes between the three industry standards in their recently ratified NASA NPR 7123.1A Systems Engineering Processes and Requirements [98], as follows: “ANSI/EIA 632 is a commercial version that evolved from the never released, but fully developed, 1994 Mil-Std 499B. It was intended to provide a framework for developing and supporting a universal SE discipline for both defence and commercial environments. ANSI/EIA 632 was intended to be a top-tier standard further defined to lower-level tier standards that define specific practices. IEEE 1220 is a second-tier standard that implements ANSI/EIA 632 by defining one way to practice systems engineering. ISO/IEC 15288, on the other hand, defines system lifecycle processes for the international set, plus for any domain (i.e., transportation, medical, commercial, et al.).”

The purpose of each major SE process model standard can be summarised as follows [99]:
- ISO/IEC 15288 – Establish a common framework for describing the lifecycle of systems.
- ANSI/EIA 632 – Provide an integrated set of fundamental processes to aid a developer in engineering or re-engineering a system.
- IEEE 1220 – Provide a standard for managing a system.

2.4.1.2 System Life cycle

As Figure 2-3 shows, the ISO/IEC 15288 standard follows the acquisition lifecycle models described in the US DoD and NASA acquisition section (2.3.3). The Institute for Electrical and Electronic Engineers (IEEE) has since standardised ISO/IEC 15288 (which they refer to as IEEE Std 15288™-2004) [100]. Moreover, the International Council on Systems Engineering (INCOSE) will adopt the 15288 standard because some of the elements have been integrated into the INCOSE Systems Engineering Handbook v3 [40]. A system life cycle is typically segmented by stages to facilitate planning, provisioning, operating, and supporting the system-of- interest; however, a typical system progresses through a series of stages where it is conceptualised, developed, produced, utilised, supported, and then retired. The 15288 Std. system lifecycle is shown in Figure 2-4 and the purpose of each stage is indicated in Table 2-1.

<table>
<thead>
<tr>
<th>LIFE CYCLE STAGES</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploratory Research</td>
<td>Identify stakeholders’ needs</td>
</tr>
<tr>
<td></td>
<td>Explore ideas and technologies</td>
</tr>
<tr>
<td>Concept</td>
<td>Refine stakeholders’ needs</td>
</tr>
<tr>
<td></td>
<td>Explore feasible concepts</td>
</tr>
<tr>
<td></td>
<td>Propose viable solutions</td>
</tr>
<tr>
<td>Development</td>
<td>Refine system requirements</td>
</tr>
<tr>
<td></td>
<td>Create solution description</td>
</tr>
<tr>
<td></td>
<td>Build system</td>
</tr>
<tr>
<td></td>
<td>Verify and validate system</td>
</tr>
</tbody>
</table>

Table 2-1: Generic life-cycle stages and their purposes
A number of lifecycle development models have been created and applied to large-scale system and software development projects used in government, industry, and academia, but most are grounded in one of three seminal models. These are 1) Royce’s *Waterfall Model* [102], Boehm’s *Spiral Model* [103], and Forsberg and Moog’s “Vee” *Model* [104]. A graphical depiction of each of these lifecycle development models is shown in Figure 2-5. Reviewing the main life cycles shows that the systems engineering is more focussed on the project, not on its procurement.
2.4.1.3 **Procurement as the new stage of life cycle**

In another sense, ISO15288 divides the Systems Engineering Life Cycle Processes into four groups; Enterprise Processes, Agreement Processes, Project Processes and Technical Processes. Figure 2-6 illustrates the groups with the included processes.
The interactions between the process groups within and between organisations are shown in Figure 2-7, where the Enterprise, Project and Technical Processes are used within an organisation while the Agreement Processes are used between organisations. The agreement processes establish the relationship and requirements between an acquirer and supplier, and provide the basis for commencing other project processes in order to arrive at an agreement to engineer, utilise, support or retire a system, and to acquire or supply related services [40].
Note that the agreement process in Defence industry is quite different to infrastructure systems because as Figure 2-1 shows (US DoD acquisition lifecycle) the Concept Refinement and Technology Development (Preliminary Design) stages are considered as a Pre-Systems Acquisition process and the System Development & Demonstration (Design) and Production & Deployment stages are mapped to the Acquisition process. Put simply, the acquisition process in Defence industry is responsible for the design and production of SoS, reflecting that DoD do not simply buy the services and products to fulfil its needs, but they are outsourced while remaining under the full surveillance and control of DoD. Alternatively, urban infrastructure systems are procured by government through engineering organisations (system developers) by different methods, as discussed before (1.2: Procurement Methods).

The agreement process in infrastructure systems involves sub-processes such as tender document specification, definition of tender evaluation plan, invitation for tenders (Expression of Interest), request for proposal, proposal evaluation, etc., which do not exist in the defence industry’s acquisition processes. Since this research is focusing on the procurement of infrastructure systems, the procurement stage is added to the system lifecycle to show how this research fits into the context of the literature and how the results and outcomes help to fill the gap in the literature. Therefore the lifecycle we work on in this research has the ‘Procurement’ stage shown as Figure 2-8Error! Reference source not found.. The procurement stage refers to the processes and activities that take place by the acquirer and supplier of a system (or SoS) to be delivered. As discussed before, in Public Private Partnership and other modern contracts the requirements are specified as service outcomes rather than prescribed system specifications. This is why the procurement stage is placed after the concept stage, where the high level system services and operations are
defined, and before the design stage, where the technical functionalities and physical requirements are specified.

![Figure 2-8: Procurement added as the new stage to the lifecycle](image)

### 2.4.1.4 Transition to a model based approach

The emphasis in traditional systems engineering on controlling the documentation and ensuring the documents and drawings are valid, complete, and consistent, and the developed system complies with the documentation. A document-based approach can be rigorous but the completeness, consistency, and relationships between requirements, design, engineering analysis, and test information are difficult to assess because this information is spread across numerous documents which makes it difficult to understand a particular aspect of the system and to perform the necessary traceability and change impact assessments. This then leads to poor synchronisation between system-level requirements and design and lower-level hardware and software design, and also makes it difficult to maintain or reuse the system requirements and design information for an evolving or variant design. Moreover, the progress of a systems engineering effort is based on the documentation status which may not adequately reflect the system requirements and design quality. These limitations can result in inefficiencies and potential quality issues that often show up during integration and testing, or worse, after the system is delivered to the acquirer [41].

Due to the problems of document based approaches, US DoD transited its systems engineering activities to model driven approaches based on ISO/IEC/IEEE 42010 standard [107], which is explained further in section 2.4.2.2 ISO/IEC/IEEE 42010. The model driven version of systems engineering is known as Model Based Systems Engineering (MBSE) which is described in detail in section 2.4.3: MBSE.

The transition from document-based systems engineering to MBSE is a shift in emphasis from controlling documentation about the system to controlling the model of the system. MBSE integrates system requirements, design, analysis, and verification models to address multiple aspects of the system in a cohesive manner, rather than a disparate collection of individual models. MBSE provides an opportunity to address many of the limitations of the
document-based approach by providing a more rigorous means for capturing and integrating system requirements, design, analysis, and verification information, and facilitating the maintenance, assessment, and communication of this information across the system’s life cycle.

2.4.2 Model Driven Architecture

Model driven approaches have been created to address the issues of Document driven Systems engineering, for example, the Model-Driven Architecture (MDA) of the OMG [108]. DSouza [109] describes MDA as “an approach to the full lifecycle integration of enterprise systems comprised of software, hardware, humans, and business practices. It provides a systematic framework to understand, design, operate, and evolve all aspects of such enterprise systems, using engineering methods and tools. MDA is based on modelling different aspects and levels of abstraction of a system, and exploiting interrelationships between these models.” These different models represent different levels of abstraction and areas of concern, so it is important that techniques should be developed for mapping between them.

2.4.2.1 Definition

Before describing Architecture Modelling, it is first important to understand what the term ‘Architecture’ means. There are many definitions of the term architecture from two different disciplines: software engineering and systems engineering; the following definitions of ‘architecture’ are taken from software engineering:

- [Schach 1997]: “modules and how they are interconnected” [110]
- [Pressman 2000]: “relationships among major components of the program” [111]
- [Sanders&Curran 1994]: “a hierarchy of components according to a partitioning method” [112]
- [OMG 2004]: “the set of significant decisions about the organisation of a software system, the selection of the structural elements and their interfaces by which the system is composed, together with their behaviour, as specified in the collaboration among the elements, the composition of these structural and behavioural elements into progressively larger subsystems and the architectural style that guides this organisation” [113]
Each definition is primarily concerned with the major elements in a system and their interrelationships and interactions. The fourth, and by far the longest definition starts to introduce the concept of evolution by mentioning ‘progressively larger subsystems’; which implies some sort of natural progression, or evolution, over time. This definition also introduces the concept of ‘architectural style’ or the way in which the architecture is developed.

The following are two more definitions of ‘architecture’ that are taken from systems engineering:

- “the structure of components, their relationships, and the principles and guidelines governing their design & evolution over time” DoDAF, 2007 [92]
- “The fundamental organisation of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution” IEEE, 2000 [114]

These two definitions have much in common with those for software engineering because they both talk about the ‘components’ in a system and their ‘relationships,’ and both mention the word ‘evolution’. However, the scope of the definition here is far wider because both definitions explicitly mention the ‘principles’ governing how the architecture is developed; this means that the systems engineering definition of architecture is concerned not just with what is produced, but also how the architecture is produced, something that was only really hinted at in the software engineering definitions. In fact, if these definitions are considered in order they represent an evolution of the term ‘architecture’ from a simple, narrow definition, to a more complete and wider definition of the term.

The term ‘architecture’ in software engineering is limited to software elements (including the interfaces) that make up a software application, while the term ‘architecture’ in systems engineering may apply to technical, social, political, financial or any other type of system. In the context of SoS engineering it is essential that these broader definitions of architecture are used.

2.4.2.2 ISO/IEC/IEEE 42010: Architecture description standard

As discussed, the concept of architecture covers the entire enterprise or SoS, and therefore architecture modelling is the key to achieving integration, consistency, effective change management, common understanding and efficient and accurate knowledge sharing in
complex domains. Architecture modelling or Architecture Description is standardised by ISO/IEC/IEEE 42010 which is discussed here.


ISO/IEC/IEEE 42010 is based upon a conceptual model – or “meta model” – of the terms and concepts pertaining to Architecture Description. The conceptual model is presented in the Standard using UML class diagrams to represent classes of entities and their relationships. Figure 2-9 captures the terms and concepts of systems and their architectures as a context for understanding Architecture Description.

![Figure 2-9: The Context of Architecture Description](image)

**System:**

The Standard takes no position on the question, “What is a system? “ In the Standard, the term system is used as a placeholder – e.g., it could refer to an enterprise, a system of systems, a product line, a service, a subsystem, or software. Nothing in the Standard depends upon a particular definition of system, so users of the Standard are free to use whatever
system theory they choose. The premise of the Standard is, “For a system of interest to you, the Standard provides guidance for documenting an architecture for that system.” [115]

**Environment:**
Every System inhabits its Environment so a System acts upon that Environment, and vice versa. A system’s Environment determines the range of influences upon the system. In the Standard, Environment is intended in the widest possible sense to include developmental, operational, technical, political, regulatory, and every other influence which can affect the architecture. These influences are categorised as Concerns.

**Stakeholder:**
Stakeholders have interests in a System; these interests are called Concerns. A system’s Purpose is one very common Concern. Stakeholders are individuals, groups or organisations holding Concerns for the System of Interest. Examples of stakeholders: client, owner, user, consumer, supplier, designer, maintainer, auditor, CEO, certification authority, architect.

**Concern:**
A Concern is any interest in the system. Examples of concerns: (system) purpose, functionality, structure, behaviour, cost, supportability, safety, interoperability.

**Architecture:**
Systems have architectures which were defined in a previous section. The Standard uses the definition provided by IEEE1471 [114] as: “fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution”.

**Architecture Description:**
An Architecture Description (AD) is an artefact that expresses an Architecture. Architects and other system stakeholders use Architecture Descriptions to understand, analyse and compare Architectures, and often as “blueprints” for planning and construction. ADs are the primary subject of ISO/IEC/IEEE 42010 and are explained in Figure 2-10.
An Architecture Description is a work product used to express the Architecture of some System Of Interest. The Standard specifies requirements on Ads where an AD describes one possible Architecture for a System of Interest. An AD may take the form of a document, a set of models, a model repository, or some other form (AD format is not defined by the Standard). The rest of the terms are defined below:

**Architecture Viewpoint:**

An Architecture Viewpoint is a set of conventions for constructing, interpreting, using and analysing one type of Architecture View. A viewpoint includes Model Kinds, viewpoint languages and notations, modelling methods and analytic techniques to frame a specific set of Concerns. Examples of viewpoints are operational, systems, technical, logical, deployment, process, information.

**Architecture View:**

---

Figure 2-10: The core of Architecture Description
An Architecture View in an AD expresses the Architecture of the System of Interest from the perspective of one or more Stakeholders to address specific Concerns, using the conventions established by its viewpoint. An Architecture View consists of one or more Architecture Models. The various views are not fully orthogonal or independent because the elements of one view are connected to elements in other views, following certain design rules and heuristics [116].

**Architecture Model:**

A view consists of Architecture Models where each model is constructed according to the conventions established by its Model Kind, typically defined as part of its governing viewpoint. Models provide a means for sharing details between views and for using multiple notations within a view.

**Model Kind:**

A Model Kind defines the conventions for one type of Architecture Model.

2.4.2.3 **Architecture Frameworks and Architecture Description Languages**

Architecture frameworks and architecture description languages (ADLs) are two mechanisms widely used in architecting. Instances of each can be specified by building on the concepts of Architecture Description presented above. The diagram below depicts the contents of an Architecture Framework.

![Architecture Framework Diagram](image)

*Figure 2-11: Architecture Framework: the basis of architecting [117]*
An architecture framework establishes a common practice for creating, interpreting, analysing and describing architecture within a particular domain of application or stakeholder community. The Architecture Frameworks are described in more detail later as one of the fundamentals of Model Based Systems Engineering. Two of the most widely used Architecture Frameworks called DoDAF and MoDAF are introduced and explained in more detail in section 2.4.4: UPDM.

An ADL is any form of expression used in Architecture Descriptions; it might include a single Model Kind, a single viewpoint or multiple viewpoints. ADLs are another fundamental of MBSE and are explained further in the next section. Examples of ADLs are Rapide, SysML, ArchiMate, ACME, xADL. UML and SysML (a UML profile for Systems Engineering) are explained in more detail in section 2.4.3.4: Modelling Standards/Languages. The diagram below depicts the contents of an ADL.

![Figure 2-12: Architecture Description Language: the mechanism for architect modelling](image)

### 2.4.3 Model Based Systems Engineering (MBSE)

Due to the limitations of document driven systems engineering which were set out above, Architecture Modelling practices are commonly used in systems engineering to address these limitations by establishing a model based environment to implement SE activities and processes. A combination of Systems Engineering processes and standards (mostly based on ISO/IEC 15288) and Architecture Description/Modelling standard (ISO/IEC/IEEE 42010 standard) resulted in the appearance of a new discipline called Model Base Systems Engineering.

“Model-based systems engineering (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” [40]. MBSE is intended to facilitate systems engineering activities that have traditionally been performed using the document-based approach and result in enhanced communications, specification and design precision, system design integration, and the reuse of system artefacts [41].

Different practitioners and researchers have tried to apply MBSE in their solution development practices; and each has focused on only a part of MBSE principles. Matthew Hause published the documentation of his efforts on applying MBSE [43] [118] [44] [119] by focusing on the Architecture Frameworks and Modelling languages, especially UML and SysML, to practice the MBSE approaches. In another study [45] the COMPASS group (Comprehensive Modelling for Advanced Systems of Systems) identified three architectural modelling techniques: Architecture Frameworks, semi-formal notations (e.g. UML, SysML, SoaML, IDEF, AADL) and formal notations (e.g. Darwin, Wright, ArchWare). In his recently published book in 2014, “SysML Distilled: A Brief Guide to the Systems Modeling Language” [46], Lenny Delligatti, considers three pillars for MBSE: Modelling Languages, Modelling Methods and Modelling tools. He has already mentioned modelling methods and modelling tools in addition to previous researches, but he has not counted the architecture frameworks. The most complete foundations of MBSE is provided by Sanford Friedenthal in his book: “A practical guide to SysML” [41]. Here, the MBSE fundamentals are referred to as standards and are categorized as: Process Standards, Architecture Frameworks, Systems Engineering Methods, Modelling and Simulations Standards and interchange and metamodelling standards.

In order to understand and define MBSE, the fundamentals of MBSE as described on the basis of the references quoted above are summarised below.

2.4.3.1 Process Standard

A primary emphasis for systems engineering standards has been developing process standards that include EIA 632 [95], IEEE 1220 [96], and ISO 15288 [97]. These standards address broad industry needs and reflect the fundamental tenets of systems engineering that provide a foundation for establishing a systems engineering approach.

The systems engineering process standards share much with software engineering practices. Management practices for planning, as an example, are similar whether it is for complex software development or systems development. As a result, there has been a significant
emphasis in the standards community on aligning the systems and software standards where practical.

### 2.4.3.2 Systems Engineering Method

A systems engineering process defines ‘what’ activities have been performed, but it does not generally give details on ‘how’ they are performed. A systems engineering method describes how the activities have been performed in terms of the types of artefacts that are produced and how they are developed. For example, an important systems engineering artefact is the concept of operations, which defines what the system is intended to do from the stakeholders’ perspective. It also depicts how the system interacts with its external systems, but it may not show any of the internal operations. Different methods may use different techniques and representations to develop the concept of operations, which is true for many other systems engineering artefacts.

Examples of systems engineering methods are identified in a Survey of Model- Based Systems Engineering Methods [42] and include IBM Telelogic Harmony [120], the Object-Oriented Systems Engineering Method (OOSEM) [121], the IBM Rational Unified Process for Systems Engineering (RUP SE) [122], the JPL State Analysis method [123], the Vitech Model-Based Systems Engineering Methodology [124] and the Dori Object-Process Methodology (OPM). Many organisations have also developed internal processes and methods, and while these methods are not official industry standards, de facto standards may emerge as they prove their value over time. The criteria for selecting a method include its ease of use, its ability to address the range of systems engineering concerns, and the level of tool support. SysML is intended to support many different systems engineering methods.

### 2.4.3.3 Architecture Framework

ISO/IEC/IEEE 42010 defines an Architecture Framework as: “conventions and common practices for architecture description established within a specific domain or stakeholder community”[107]. By building on the requirements in IEEE 1471 for specifying architecture descriptions, the draft standard also specifies requirements for architecture frameworks [114] which may be summarised as a framework that must identify a set of stakeholders, a set of their architecture concerns, and a set of viewpoints framing these concerns. According to the draft standard, a framework must also identify any correspondence to be enforced between views resulting from applying those viewpoints. The Zachman framework [125] was introduced in the 1980s to define enterprise architectures; it defines a standard set of
stakeholder perspectives and a set of artefacts that address fundamental questions associated with each stakeholder group.

WG42, a working group in ISO/IEC/IEEE 42010 management team, have gathered a list of Architecture Frameworks in a survey. Nearly 60 Architecture Frameworks are named in this survey which is published here [126]. Examples of Architecture Frameworks are DoDAF (Department of Defense Architecture Framework), TRAK (The Rail Architecture Framework), MoDAF (Ministry of Defence Architecture Framework), TOGAF, Kruchten’s 4+1 View Model. DoDAF and MoDAF are designed to focus on system acquisition, so they will be explained and analysed in UPDM (Unified profile for DoDAF and MoDAF) section (2.4.4).

2.4.3.4 Modelling Standards/Languages

Modelling standards provide a common language for describing systems. The Integration Definition for Functional modelling (IDEF0) [127] was issued by the National Institute of Standards and Technology in 1993. The OMG SysML specification was adopted in 2006 by the Object Management Group as a general purpose graphical systems modelling language that extends the Unified Modelling Language (UML) and is the main language used in this research. Several other extensions of UML have been developed for specific domains. The Unified Profile for DoDAF/MODAF (UPDM) is being developed to describe the system of systems and enterprise architectures that comply with DoDAF and MODAF requirements. The foundation for the UML-based modelling languages is the OMG Meta Object Facility (MOF) [128], which is a metamodelling standard used to specify other modelling languages.

As mentioned above, the languages used in combination with Architecture Frameworks to develop architecture models are called Architecture Description Languages (ADLs). According to a survey conducted by Ivano Malavolta et al. [129] there are almost 50 ADLs in use by different IT companies and architecture modellers. A list of these ADLs can be accessed on their web site [130].

2.4.3.5 Interchange and Metamodelling Standards

Model and data interchange standards are a critical class of standards which support model and data exchange among tools. Within the OMG, the XML Metadata Interchange (XMI) specification [131] supports the interchange of model data when using an MOF-based language such as UML, SysML, or another UML profile. Another data exchange standard for interchange of systems engineering data is ISO 10303 (AP233) [132].
2.4.3.6 Modelling Tools

Modelling tools are designed and implemented to comply with the rules of one or more modelling languages, to enable practitioners to construct well-formed models in those languages. Modelling tools are distinct from diagramming tools such as Microsoft Visio and Power Point because there is no model underlying those diagrams that ensure automated consistency between them; but with a modelling tool, a model is created which means a set of elements and relationships between elements, and a set of diagrams that serve as views of the underlying model. The correspondence and conformance of the developed model to the language metamodel is kept by the tool to ensure well-formedness and consistency.

Several commercial tool vendors and non-profit consortiums have created modelling tools for various modelling languages which vary in cost, capability, and compliance with the specifications of the modelling language. Selecting the best tool based on the project’s specific needs and cost constraints should be part of the MBSE adoption process. Following is a list of commercial-grade modelling tools:

- Artisan Studio Integrity Modeller (Vendor: PTC)
- Enterprise Architect (Vendor: Sparx Systems)
- Magic Draw (Vendor: No Magic)
- Rhapsody (Vendor: IBM Rational)

In this research Magic Draw is used as the modelling tool because it provides all the functionalities required in this research and is also cheaper than other tools (Artisan Studio Integrity Modeller).

2.4.4 UPDM

Since the introduction of DoDAF, military architectural frameworks have been extended, resulting in several different versions. A short list includes MODAF (UK), NAF (NATO), DNDAF (Canada), MDAF (Italy), AGATE (France), and ADOAF (Australia). Each one adds to, redefines and/or clarifies the concepts, views, viewpoints and concerns contained within Military Architectural Frameworks, with the intention of improving procurement, planning, and implementation of military systems. However, supporting multiple and sometimes divergent frameworks leads to problems for industry, military organisations and tool vendors alike because incompatible frameworks cause interoperability problems between governments because models cannot be exchanged. Interchange, even between modelling
tools supporting the same framework, is difficult, if not impossible due to the different underlying implementations. Finally, having to support several constantly changing framework formats means that modelling tool vendors have a support nightmare [118].

The Unified Modelling Language (UML) and the recently created Systems Modelling Language (SysML) can be used as an underlying mechanism for all of these frameworks. For example, DoDAF provides guidance on using UML [133] and the MODAF Meta-Model (M3) is expressed using UML Notation [134]. This makes it feasible to work towards a standardised UML/SysML profile for these Military Architectural Frameworks.

In order to address these problems, OMG proposed using a unified profile to serve as an international architectural modelling standard. This UPDM initiative was formed by members of INCOSE (International Council on Systems Engineering) and OMG to create a Unified Profile for DoDAF and MODAF (UPDM) using UML/SysML. Members of the UPDM Group are the tool vendors Adaptive, Artisan Software Tools, EmbeddedPlus, No Magic, Sparx, Visumpoint, members of industry ASMG, BAE Systems, Generic AB, Lockheed Martin, Mitre, Raytheon, Rolls Royce, and representatives from the DoD, MOD, and NATO (North Atlantic Treaty Organization).

The goals of UPDM are to enhance the quality, productivity, and effectiveness associated with the enterprise and system of systems architecture modelling, promote the reuse and maintainability of the architecture model, improve tool interoperability and communications between stakeholders, and reduce the training impacts due to different tool implementations and semantics [135]. Using the UML XML Metadata Interchange (XMI) interchange format, virtually all UML tools will be able to exchange models. The standardisation of model data and UML/SysML mapping means that both tool vendors and industry can provide models in a single format.

By satisfying the requirements of UPDM, a profile (a set of stereotypes/concepts) consisting of all the metamodel elements (stereotypes or concepts) of DoDAF and MoDAF have been created. These stereotypes are directly or indirectly the subtypes/children of an element called the ‘UPDM element’. The Domain Meta Model (DMM) for UPDM was then developed to keep the UPDM rules by defining the relationship between stereotypes and other types of constraints. Many elements of DoDAF and MoDAF are the same, so concepts common to both DoDAF and MODAF were captured in a package called ‘Core’, with ‘DoDAF’ and ‘MODAF’ packages also being created for their specific elements.
Figure 2-13 illustrates a piece of Domain Meta Model that captures the Acquisition viewpoint no 1 of MoDAF, which is equivalent to Project Viewpoint no 1 of DoDAF, and includes the elements of DoDAF and MoDAF. As shown, all elements have the ‘UPDM2 Stereotype’ which are taken from either MoDAF e.g. ‘ProjectOwnership’ or DoDAF e.g. ‘ActualOrganizationalResource’. Note that UPDM has defined some new elements; for instance ‘OrganizationalProjectRelationship’ is an element defined by UPDM.

It is important to stress that UPDM is not a new Architectural Framework, it provides a consistent and standardised way to describe DoDAF and MODAF architectures in UML-based tools, as well as a standard for interchange.

Table 2-2 includes an exemplar list of UPDM elements and its mapping to DoDAF and MoDAF elements. Table 2-3 indicates how corresponding DoDAF and MoDAF perspectives are mapped together.

<table>
<thead>
<tr>
<th>DoDAF Meta Model element</th>
<th>UPDM Profile element</th>
<th>MODAF Meta Model element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>Activity</td>
<td>Activity Composition</td>
</tr>
</tbody>
</table>
### Table 2-3. Mapping DoDAF and MoDAF perspectives

<table>
<thead>
<tr>
<th>DoDAF Perspective</th>
<th>MoDAF Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capability viewpoints (CV)</td>
<td>Strategic Viewpoints (StV)</td>
</tr>
<tr>
<td>Operational Viewpoints (OV)</td>
<td>Operational Viewpoints (OV)</td>
</tr>
<tr>
<td>Project Viewpoints (PV)</td>
<td>Acquisition Viewpoints (AcV)</td>
</tr>
<tr>
<td>Services Viewpoints (SvcV)</td>
<td>Service Oriented Viewpoints (SOV)</td>
</tr>
<tr>
<td>Systems Viewpoints (SV)</td>
<td>Systems Viewpoints (SV)</td>
</tr>
<tr>
<td>Standards Viewpoints (StdV)</td>
<td>Technical Standards Viewpoints (TV)</td>
</tr>
<tr>
<td>All Viewpoints (AV)</td>
<td>All Viewpoints (AV)</td>
</tr>
<tr>
<td>Data And Information Viewpoints (DIV)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### 2.5 Research Gap and hypothesis

Rich Hilliard, the editor and chair of ISO/IEC IEEE 42010, has published the lessons learnt while developing this standard [115]; he says “The most important lesson learned from the past 20 years of architecture framework development is this: you will never finish defining the metamodel of a given domain of interest”. In another paper [116] he writes “For any of the numerous published frameworks, it is trivial to identify gaps in their polished metamodels.”

In the next subsections the UPDM is mapped to the system lifecycle to indicate where this research is focused, and in the later subsection, the acquisition perspective which is the focus of this study is analysed to express the research gap.

#### 2.5.1 Mapping UPDM to the System Lifecycle
In order to understand the purpose of the DoDAF/MoDAF viewpoints better and to triangulate the focus point of this research, the main viewpoints are mapped to the generic system life cycle, as shown in Figure 2-14. The horizontal axis represents the stages of the system life cycle, while the vertical axis indicates the levels of enterprise hierarchy. This figure justifies why the ‘Vee’ lifecycle looks like a ‘V’.

CVp stands for the Capability Viewpoint and indicates the goals and visions of an enterprise and the capabilities needed to achieve them.

OVps are Operational Viewpoints which capture the system usability concerns, user requirements, and operational scenarios. These high level operations do not explicitly indicate system functions, they conceptually define the system in the concept definition stage, so they are often called ‘Concept of Operations’ and are known as CONOPs. As the figure shows, they are located at the junction point of the Concept definition stage of the system lifecycle and Operational level of the enterprise.

Once the user requirements and operational scenarios have been defined, they will serve as inputs to the Acquisition stage so they are used to express the requirements of the acquirer in the acquisition contract. Acquisition perspective has (at least means to have) relationships and connections to the remaining perspectives because the products developed in the
Capability and Operational perspectives are the main materials used to build the acquisition materials; the System and Service perspectives express the system designed as a response to acquirer requirements and are sent to acquirers through this channel, so it is the input/output gateway for the acquirer and the suppliers i.e. it is the bridge between acquirer and suppliers (see Figure 2-15). Consequently, this perspective covers almost all the vertical levels of enterprise layers in Figure 2-14.

SVps represent the Service Viewpoints that are used to translate user requirements to system functional requirements and then to system specifications. The system components and their interconnectivity are defined here for use in production. SVp-03 maps the system parts to the system functional requirements, so it is used for system verification i.e. do the created and integrated components provide the defined functionalities? SVp-05 maps the system functions to operational scenarios/user requirements and OVp-04 maps the operational scenarios to the defined capabilities, so they will be used to validate the system, i.e., do the system functions meet the defined operational scenarios and do the operational scenarios meet the defined capabilities?

2.5.2 Analysing the Acquisition perspective

As shown in Figure 2-14 the focus of this study is the ‘procurement of’ the SoS, not the SoS itself, so in this section the Acquisition perspective of UPDM (Project perspective of DoDAF / Acquisition Perspective of MoDAF) is analysed to assess its effectiveness.

The best way to assess the effectiveness of UPDM is to validate it against the standard systems engineering processes defined in ISO/IEC 15288, so each perspective should be compared to its corresponding group of processes. Figure 2-15 indicates the acquisition process as defined by ISO/IEC 15288. In order to compare these processes to UPDM acquisition perspective the Piece of metamodel dealing with the acquisition perspective is shown in Figure 2-16. The acquisition perspective has three viewpoints named and described in Table 2-4.
Figure 2-15: Acquisition Process Context Diagram in ISO/IEC 15288 [40]

Figure 2-16: Summary of metamodel elements of (Acquisition) Project perspective

Table 2-4: (Acquisition) Project viewpoints of UPDM [135]

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Description</th>
</tr>
</thead>
</table>
PV-1: Project Portfolio Relationships
It describes the dependent relationships between the organizations and projects and the organizational structures needed to manage a portfolio of projects.

PV-2: Project Timelines
A timeline perspective on programs or projects, with key milestones and interdependencies.

PV-3: Project to Capability Mapping
The capabilities of programs and projects are mapped to show how the specific projects and program elements help to achieve a capability.

The Project models developed by project perspective of UPDM metamodel 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 the capabilities rendered by this project to be in place?

This comparison clearly shows that the acquisition perspective of the current version of UPDM (v 2.1) does not cover all the acquisition processes defined in ISO/IEC 1528. Moreover, as discussed in section 2.1 (PPP Procurement Problems), there are many other acquisition related concerns, including financial matters, e.g., cost and revenue calculation; risk management aspects, e.g., risk calculation and risk allocation; and accountability issues, e.g. responsibilities of the contract parties. The Acquisition perspective metamodel does not have the elements to cover and address those concerns, which reflects the inadequacy of this perspective in infrastructure procurement projects.

DODAF and MoDAF were developed by people who oriented towards using the Project/Acquisition perspective to develop project modelling rather than modelling the complex organisational structure needed for the project, so this seems to be the reason why the UPDM acquisition perspective is designed this way. However, as discussed, in order for
this perspective to be useful in the infrastructure systems procurement, improvements are needed.

2.5.3 Research goal

Architecture frameworks have existed since the 1970s—even before John Zachman coined the term “framework for information systems architecture”. The metamodel of frameworks has evolved as our understanding of enterprises, and 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” [116]. 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 on and therefore 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.

This research hypothesizes that the current version of UPDM, as an internationally accepted unified profile (published by OMG®), is the most widely accepted framework for acquisition (used in more than 60 countries) and with the most completed metamodel (as it covers DoDAF, MoDAF and NAF) which can be used to acquire infrastructure systems. However, this metamodel cannot completely cover this domain or address all the concerns of the stakeholders. Therefore, this thesis aims at identifying the main stakeholders of this domain and their concerns, and then extending UPDM to resolve its inadequacies. Consequently, UPDM would become capable of developing architecture models of the infrastructure acquisition domain. So, as discussed in section 1.4, the main goal of this study is to develop a metamodel which provides a standardized conceptual definition of the PPP domain. This metamodel is meant to be used in developing a modelling language which is customized for modelling the PPP projects.

The extension mechanism used to extend UPDM with new elements and viewpoints is profiling. The new profile elements will then be mapped to SysML to create the Procurement
Modelling Language (PML) for infrastructure procurement. The Profiling and UML-based DSLs are described in next section.

2.6 DSL development and Evaluation

2.6.1 UML Profiling mechanism

UML is a general purpose visual modelling language for specifying, constructing, and documenting the artefacts of systems that can be used with all major application domains and implementation platforms. It has been widely adopted by industry and academia as the standard language for describing software systems. However, since UML is a general-purpose notation, it may not be suitable for modelling some particular specific domains (e.g. web applications or business processes), so specialised languages and tools may be more appropriate.

OMG defines two possible approaches for defining domain-specific languages. The first one is based on the definition of a new language, an alternative to UML, using the mechanisms provided by OMG for defining object-based visual languages (i.e., the same mechanisms that have been used for defining UML and its metamodel). In this way the syntax and semantics of the elements of the new language are defined to fit the domain's specific characteristics. The problem is that standard UML tools cannot deal with such a new language, which is why PML has been developed as a UML profile in this study.

The second alternative is based on the particularisation of UML by specialising some of its elements, imposing new restrictions on them but respecting the UML metamodel, and without modifying the original semantics of the UML elements (i.e., the properties of the UML classes, associations, attributes, etc., will remain the same, but new constraints will be added to their original definitions and relationships).

UML provides a set of extension mechanisms (stereotypes, tag definitions, and constraints) for specialising its elements and allowing customised extensions of UML for particular application domains. These customisations are sets of UML extensions grouped into UML profiles, however, the UML profiles for a specific domain cannot play the role of a specialised tool; they are just specialised metamodels.

A UM profile is a predefined set of Stereotypes, Tagged values, Constraints and notation icons that collectively specialise and tailor the UML for a specific domain or process. A
profile does not extend UML by adding new basic concepts, it provides conventions for applying and specialising standard UML to a particular environment or domain [136]. In this research, profiles are used to extend the UPDM and SysML by specialising their elements to have concepts specified to the procurement domain. The created profile is the basis of the DSML (Domain Specific Modelling Language) which plays the role of Acquisition perspective of UPDM.

2.6.2 The Four-Layer Metamodel Hierarchy

When dealing with meta-layers to define languages, there are generally three layers that must always be taken into account: [137]

a. the language specification, or the metamodel,
b. the user specification, or the model, and
c. objects of the model.

This structure can be applied recursively many times so that we get a possibly infinite number of meta-layers; a model that is instantiated from a metamodel can in turn be used as a metamodel of another model in a recursive manner. This is what happens with UML and MOF, that is, in the first recursion MOF as a metamodel stays at level ‘a’ as a language specification and creates UML as a model at level ‘b’. So from the perspective of MOF, UML is viewed as a user (i.e., the members of the OMG that have developed the language). In the second recursion UML stays at level ‘a’ where it acts as a language specification (metamodel) from which users can define their own models.

In order to simplify the understanding of the layers and clarify the locations of MOF and UML, OMG have introduced the Four-Layer Metamodel Hierarchy by showing the two mentioned recursions together and then adding a new layer called ‘meta-metamodel’. “In the four-layer metamodel hierarchy, MOF is commonly referred to as a meta-metamodel, even though strictly speaking it is a metamodel [137].” These layers are named top down by M3 to M0.

- M3: The meta-metamodelling layer forms the foundation of the metamodeling hierarchy. The primary responsibility of this layer is to define the language for specifying a metamodel. This layer is often referred to as M3, and MOF is an example of a meta-metamodel. The constituent elements of the MOF metamodel are grouped
in a so called ‘Infrastructure Library’ because they are the infrastructure of the OMG Objet Orientation.

- **M2:** A metamodel is an instance of a meta-metamodel, meaning that every element of the metamodel is an instance of an element in the meta-metamodel. The primary responsibility of the metamodel layer is to define a language for specifying models. This layer is often referred to as M2; UML and the OMG Common Warehouse Metamodel (CWM) are examples of Metamodels. In effect, each UML metaclass is an instance of an element in Infrastructure Library.

- **M1:** A model is an instance of a metamodel where the things that are being modelled reside outside the metamodel hierarchy. This layer is often referred to as M1. A user model is an instance of the UML metamodel.

- **M0:** The metamodel hierarchy bottoms out at M0, which contains the run-time instances of model elements defined in a model. Level M1 is distinct from M0, as in the slogan: The map is not the territory.

The concepts discussed in ISO/IEC/IEEE 42010 can be mapped to these 4 layers as shown in Figure 2-17 [107]. Note that the ISO42010 spans M2 and M3, and specifies both conventions on Architecture Descriptions, and conventions on specifying Viewpoints and Model Kinds. Viewpoints (constituent pieces of Architecture Framework) and Model Kinds (sections of Architecture Description Language) are located at M2. So the Architecture Frameworks, e.g. DoDAF and MoDAF and their combinations UPDM, and Modelling Languages, e.g. UML and SysML are metamodels located at M2. The View and Model are instantiations of the Viewpoint and Model Kind, respectively, and which contribute in developing the architecture description which is at M1.
2.6.3 Development of Domain Specific Languages

DSL development studies show that the development process varies for different DSLs that are developed in different application contexts because the order in which these activities need to be performed and the exact steps that must be executed to perform the activities can differ greatly, which is why a systematic process, including all the required activities, is useful to guide DSL developers in any case. In this research, the systematic and generic approaches to DSL development can be applied to different application domains, are gathered (Table 2-5: Systematic approaches for DSL/Metamodel creation), and then a customised DSL development process is tailored to create the DSL (Figure 3-3).

Figure 2-18 illustrates the DSL artefacts, so this thesis provides a customised method to develop these artefacts and create the final outcome of the research which is a DSL for Infrastructure Procurement. This language constitutes of two main parts: 1) the abstract syntax or Language model, and 2) the concrete syntax.
The DSL’s *language model* specifies elements from the DSL’s target domain; in essence the language model is a composite model consisting of three sub-models. The *core language model* captures all relevant domain abstractions and specifies the relations between these abstractions which refer specifically to elements of the DSL’s target domain.

*The language model constraints* express invariants on elements of the core language model and/or on relations between those elements.

The *DSL behaviour specification*, sometimes referred to as dynamic semantics, is part of the language model and defines how the DSL language elements can interact at runtime. This behaviour can be specified in many different ways, ranging from high-level control flow models, over detailed behavioural models, to a precise textual specification.

As well as an abstract syntax, each DSL needs a *concrete syntax* to use the DSL in a certain system environment. A concrete syntax represents the abstractions defined through the DSL’s abstract syntax, and each DSL can have multiple concrete syntaxes, e.g. a graphical syntax and a textual syntax. The concrete syntax serves as the DSL’s interface.

![Diagram](image)

**Figure 2-18: Domain Specific Language artefacts [138]**

According to Strembeck [138], three main DSL engineering processes are identified in DSL development projects:

1. *Language model driven*: In this type of DSL engineering process, the definition of the language model drives DSL development. That is, the core language model (abstract syntax) is defined first to reflect all relevant domain abstractions, then the concrete
syntax is defined along with the DSL’s behaviour, and finally the DSL is mapped to the platform/infrastructure on which the DSL runs.

2. *Mockup language:* To raise the participation of domain experts, DSL development can begin by designing the concrete syntax and then distilling the abstract syntax and semantics.

3. *Extract DSL from existing system:* Sometimes an existing software system should (ex post) be provided with a DSL which means the domain abstractions for the DSL can be derived directly from the existing system. In this case it makes sense to first elicit the language model elements from the abstractions given in that system.

This thesis uses the first method (language model driven) to develop the DSL. The language model-driven process is well suited for explanatory purposes because it proceeds in a top–down fashion which makes it is easy to understand and follow in documentation. Thus, even if the DSL is defined using some other tailored process variant, it makes sense to document or explain the DSL with the language model-driven process. Strembeck writes “In our experience, the language model-driven process is also well suited to be applied to small projects, where the DSL developers are domain experts themselves and in which the DSL is developed from scratch (for example, when developing technical DSLs for software developers)” [138].

Table 2-5 indicates the list of systematic and generic approaches used to tailor the DSL development process to this project, while Figure 2-6 provides examples of DSL created using those approaches. These methods are used in the next chapter (3.2.3) to tailor a customised process for developing and verifying the DSL artefacts.

<table>
<thead>
<tr>
<th>Source name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>An approach for the systematic development of domain-specific languages [138]</td>
<td></td>
</tr>
<tr>
<td>Initial Report on Guidelines for Architectural Level SoS Modelling (COMPASS) [45]</td>
<td></td>
</tr>
<tr>
<td>FAML: A Generic Metamodel for MAS Development [139]</td>
<td></td>
</tr>
<tr>
<td>Design and validation of a metamodel for metacognition support in artificial intelligent systems [140]</td>
<td></td>
</tr>
<tr>
<td>Development and validation of a Disaster Management Metamodel (DMM) [141]</td>
<td></td>
</tr>
<tr>
<td>A Systematic Approach to Domain- specific Language Design Using UML [142]</td>
<td></td>
</tr>
</tbody>
</table>
2.6.4 Evaluation of Metamodels and DSLs

The quality of a metamodel is measured based on how it responds to the needs of the domain practitioners. The types of validation techniques and how to perform them must be determined; including the best criteria for determining the best type of validation technique. These criteria can be determined according to the type of metamodels and the goal of its development (e.g. agent-based modelling, semantic and conceptual modelling, mathematical and statistical modelling). Commonly used metamodel evaluation techniques are shown in Table 2-7. In this study a variety of evaluation metrics are used to assess the metamodel in several aspects.

<table>
<thead>
<tr>
<th>Source name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>In this paper a text analysis software called AntConc is used to mine these documents. This analysis in to find the most frequently used terms in the guidelines and ensure their existence in the developed metamodel. As an example, this method is used to analyse the Systems engineering guidelines to assess the availability of DoDAF metamodel elements.</td>
<td></td>
</tr>
<tr>
<td>Assessing the Quality of Metamodels [150]</td>
<td>The validation technique proposed in this paper assesses the five properties of a metamodel: <strong>Functionality</strong>, <strong>Reusability</strong>, <strong>Understandability</strong>, <strong>Extendibility</strong> and <strong>Structure wellness</strong>. These properties are determined by calculating and weighting 6 metamodel characteristics called: Modelling concept size, Hierarchy, Coupling, Intension, Inheritance and Abstract metaclass size.</td>
</tr>
<tr>
<td>An Evaluation Framework for MAS Modelling Languages based on Metamodel Metrics [151]</td>
<td>The metamodel is applied in a variety of real cases and then according to the number of metamodel and model elements, the following quality properties are quantitatively calculated: <strong>Availability</strong>, <strong>Specificity</strong> and <strong>expressiveness</strong>.</td>
</tr>
</tbody>
</table>
| Verification and Validation of Simulation Models [152] | This paper introduces four validation techniques:  
1. Comparison against other models: Derived concepts of the developed metamodel are **compared to concepts of other** existing similar domain models or metamodels.  
2. Face validity: the process of persuading **subject-matter experts** that the model behaves reasonably; i.e. asking those who understand the domain application whether the model and/or its behaviour is reasonable.  
3. Multistage validation: combining three historical methods of **rationalism**, **empiricism** and **positive economics** into a multistage process of validation.  
4. Tracing: the behaviour of different types of specific entities in the model is traced (followed) through the model to determine whether the **logic of the model** is correct and if the necessary **accuracy** is obtained. |
| Meta-Model Validation and Verification with MetaBest [153] | This paper classifies the V&V approaches to three categories: **unit testing**, **specification based testing** and **reverse testing**. The approaches proposed here can validate a model against its generating metamodel. |
| Quality Attributes for Software Metamodels [154] | This paper is an adaption of ISO/IEC 9126 to create a customised quality model called QM4MM (Quality model for MetaModels). All six characteristics (Functionality, Reliability, Useability, Efficiency, Maintainability and Portability) are present but the definitions are adapted to the metamodel field and some sub-characteristics that are not relevant to the metamodels are eliminated. |
| ISO/IEC 9126 [155] | The ISO/IEC 9126 quality model is defined by the general characteristics of software which are further refined into sub-characteristics and then decomposed into attributes yielding to a multi-level hierarchy. The main idea behind this standard is to define a quality model and its use as a framework for software evaluation. The main characteristics defined by this standard are: Functionality, Reliability, Useability, Efficiency, Maintainability and Portability. |
| Validation of a security metamodel for development of cloud applications [156] | The validation method proposed here checks whether the automatically generated instances of the metamodel conform to the metamodel rules written in OCL (Object Constraint Language). |
| Feature selection for fluency ranking [157] | The technique used here will evaluate the importance of individual concepts in the developed metamodel. The most useful concepts are those that are used most frequently. |
3. Chapter 3: Methodology

“Design is where science and art break even”

(Robin Mathew)

3.1 Design Science Research

Design activities are central to most applied disciplines. As information systems (IS) consist of inherently mutable and adaptable hardware, software, and human interfaces, they provide many unique and challenging design problems that call for new and creative ideas. Design science, as conceptualised by Simon [158], supports a pragmatic research paradigm where innovative artefacts are created to solve real-world problems, so design science research focuses on the IT artefact with a high priority on relevance in the application domain.

Figure 3-1 borrows the IS research framework provided by Hevner in 2004 [159] and overlays a focus on three inherent research cycles. The Relevance Cycle bridges the contextual environment of the research project with the design science activities. The Rigor Cycle connects the design science activities with the knowledge base of scientific foundations, experience, and expertise that informs the research project. The central Design Cycle iterates between the core activities of building and evaluating the design artefacts and processes of the research. These three cycles must be present and clearly identifiable in a design science research project [160].

Figure 3-1: Design Science Research Cycles [159]

The methodology of this research is organised according to the cycles of design science.
Figure 3-2 illustrates the research methodology adapted from Figure 3-1

Figure 3-2: Research methodology based on design science cycles

To clarify and facilitate understanding of the methodology, it is divided into phases and shown as a linear process, as illustrated in Figure 3-3. The phases and process of each phase are explained in the following.
3.2 Problem Identification and Solution Proposal

3.2.1 Problem identification

The relevance cycle initiates design science research by reviewing the literature to find the research problems. So a literature review on the PPP domain is carried out to identify the inherent problems and challenges in the PPP projects to be tackled in this research. This step is provided in 2.1 (PPP Procurement Problems) and concluded by 2.2 to explain the importance of transparency in PPP projects.

The main problems with PPP projects are their complex processes and regulations which are difficult to follow, and the constituent elements of PPP projects are highly interdependent such that any change in one part of the project is distributed across the whole project and affects other project elements. For example, a change in estimating the project costs changes all the estimations of value for money and the economic viability aspects of the project; or a change in the risk allocation table can determine the winning bid by decreasing its proposed
costs or increasing its benefits. The existing procurement management methods are document based i.e. the project documentation and system life cycle steps are paper documents (or an electronic version of paper). Tracing the changes in documents and keeping them consistent is very time consuming and error prone, which means document based methods are not suitable for managing complex projects like PPP procurements.

The best practices for model based approaches are provided by US DoD and NASA and they are based on using the architecture frameworks and modelling languages. UPDM is developed based on two defence acquisition frameworks (DoDAF and MoDAF) that are used as a unified architecture framework which covers the whole enterprise, including the systems and procurement of those systems. However, as discussed in 2.5, UPDM does not meet all the concerns of procurement stakeholders so this research proposes a model driven approach which is the development of a metamodel that fully covers the PPP domain and can satisfy stakeholder concerns. The metamodel means it can be used as the abstract syntax of a Domain Specific Language so PML can be used by domain practitioners to document the project phases as integrated and consistent models.

3.2.2 Proposing a solution

The proposed solution which will be achieved through the research methodology is specified as below:

1. The solution is in the form of a Modelling Language (a metamodel as the abstract syntax which is implemented by a SysML profile as its user interface), so it will be used by practitioners (procurement stakeholders) to create models (views) of the procurement domain. This metamodel is called the Procurement Metamodel (PMM) and the modelling language is referred to as the Procurement Modelling Language (PML).

2. This PMM will not be created in isolation because the profile will be integrated to the body of a unified internationally accepted profile (UPDM).

3. This PML will be used as the Acquisition Perspective of UPDM, so it must be fully integrated to UPDM and its viewpoints should be connected and traced to UPDM viewpoints.

4. Domain specificity: PML means to be specific to PPP contracts, but it must be independent of any type of contract, project, sector or country.
This PML must conform to the ISO42010 standard so it should be created based on the instructions of this standard.

The mapping of ISO/IEC/IEEE 42010 to the 4-layers modelling infrastructure of OMG was discussed in 2.6.2 and shown in Figure 2-17. As the OMG specifications state, [137] “It should be noted that we are by no means restricted to only these four meta-layers, and it would be possible to define additional ones.” The main deliverable of this study is the Procurement Modelling Language which is specified to the Procurement domain, it is created based on UML and SysML which are domain independent and general purpose languages. In order to express the distinction between the specificity of the PML and general purpose languages, a new layer called M2’ (M2 prime) is created to host the PML. As Figure 3-4 shows, the Procurement Metamodel (PMM) expands the UPDM metamodel and the Procurement SysML Profile (PSP) implements this metamodel using SysML.

![Diagram](image)

**Figure 3-4: Putting the research deliverable into the context of existing literature**

The main artefacts of a DSL are described in 2.6.3 and are shown in Figure 2-18. In this section those generic artefacts are specialised to this research to explain the PML and its
parts. The artefacts of PML which are the main products of this research are illustrated in Figure 3-5.

![Diagram showing the Artefacts of the Procurement Modelling Language (PML)](image)

**Figure 3-5: Artefacts of the Procurement Modelling Language (PML)**

The target domain of the PML is the infrastructure procurement domain; a modelling language which consists of Abstract Syntax and Concrete Syntax. The Abstract Syntax is the Procurement Metamodel (PMM) which is concretised by the Procurement SysML Profile (PSP) as a concrete syntax. PMM has three parts: 1) the core language model which consists of the domain concepts and their relationships (domain constructs); 2) rules and constraints of the procurement domain; and 3) the modelling process guide for modellers which determines the order of the diagrams and the modelling steps.

### 3.2.3 Tailoring a development and validation process to the project’s context

A variety of systematic methods to develop, verify, and implement metamodels were reviewed in 2.6.3. Each method focuses on a particular artefact of the language, for example, the method provided by Beydoun [141] can be used to develop and verifying the metamodel (abstract syntax), while Silingas [144] provides a method for developing the SysML based concrete syntax for a given metamodel. To develop and verify the deliverables of this research (PML artefacts) a method needs to be tailored to its context as the development and validation process. For this purpose, the methods provided are critically analysed and the suitability of each method is investigated. So, each method has contributed in to the right part of the customized tailored method.
Firstly, the structure of the language and its main constituent parts should be identified. The well cited paper by Strembeck and Zdun ‘An approach for the systematic development of domain-specific languages [138]’ is used for this purpose as it provides a complete literature review on the domain specific languages, different DSL types and the techniques of their creation. The authors have performed an in depth analysis of 14 DSL projects. Although this paper clearly explains the main artefacts of the DSLs and their purpose, it doesn’t provide a detailed method for creating each artefact. So, this paper is only used for identification of the DSL main artefacts. As shown in Figure 3-5 the main DSL parts are the metamodel (abstract syntax) and the profile (concrete syntax). So, other methods are investigated to find a detailed method for developing these two main artefacts.

The metamodel is the core of the language and has to be developed first. Beydoun et al in [139] have introduced a detailed and tested method for developing the metamodel for a given domain. This method is then used by Othman and Caro in two different studies for developing metamodels for disaster management [141] and metacognition support [140], respectively. The development processes used in these studies are detailed enough to be practical and generic enough to be replicated in this research, so this method is used for the metamodel development. However, the suggested method is used for the domains a with small number of fragments (viewpoints); the disaster management domain has 4 and the metacognition domain has 3 viewpoints; also, these fragments are already known and they don’t need to be identified by analysing the domain. The PPP domain is a very wide domain which requires to be broken down into many viewpoints, and also, there is no standard breakdown structure for this domain. Therefore, two other methods by Hilliard ‘Architecture description template for use with ISO/IEC/IEEE 42010:2011 [117]’ and Holt et. al ‘Initial Report on Guidelines for Architectural Level SoS Modelling (COMPASS) [45]’ are used to break the PPP domain into fragments. The method suggested by Beydoun is used to create each fragment and the method provided by Holt et. al ) [45] is used to integrate the fragments and create the whole PPP metamodel.

The studies discussed above are all focused on the metamodel development, but none of them consider implementing the metamodel by concrete symbols and turn it into a modelling language. So, a study conducted by Brucker ‘Metamodel-based UML Notations for Domain-specific Languages [143]’ is employed to develop the concrete syntax by UML/SyML notations. This study does not explain how the abstract syntax should be created, so the process assumes that the metamodel is ready to be mapped to the concrete syntax. It was also
mentioned before that the PPP metamodel should be integrated to the UPDM metamodel, so before developing the concrete syntax a study done by Selic [142] is used to link the PMM to UPDM.

As one of the aims of this study is to practically apply the modelling language to PPP real cases, the language has to be implemented in a modelling tool/environment. Silingas et. al have published the method of how a language can be implemented in the Magic Draw tool. This paper (Domain Specific Modelling Environment Based on UML Profiles [144]) is finally used to implement the concrete syntax by stereotypes, creating customized SysML diagram frames and configuring the modelling environment.

The combination of methods described creates the customized method that is used in this study. Table 3-1 indicates the contribution these systematic methods make to the tailored method. The tailored process is shown in Figure 3-3 and is explained in detail in the following sections.

<table>
<thead>
<tr>
<th>Source name</th>
<th>Contribution to our method</th>
</tr>
</thead>
<tbody>
<tr>
<td>- An approach for the systematic development of domain-specific languages [138]</td>
<td>● Identify the type of DSL</td>
</tr>
<tr>
<td>- Initial Report on Guidelines for Architectural Level SoS Modelling (COMPASS) [45]</td>
<td></td>
</tr>
<tr>
<td>- FAML: A Generic Metamodel for MAS Development [139]</td>
<td>● Breaking the domain into fragments (Viewpoints)</td>
</tr>
<tr>
<td>- Development and validation of a Disaster Management Metamodel (DMM) [141]</td>
<td></td>
</tr>
<tr>
<td>- Design and validation of a metamodel for metacognition support in artificial intelligent systems [140]</td>
<td>● Conceptual definition of each viewpoint</td>
</tr>
<tr>
<td>- A Systematic Approach to Domain-specific Language Design Using UML [142]</td>
<td>● Linking the Abstract Syntax to other metamodels (UPDM)</td>
</tr>
<tr>
<td>- Metamodel-based UML Notations for Domain-specific Languages [143]</td>
<td>● Developing the Concrete Syntax (profile)</td>
</tr>
</tbody>
</table>
3.3 Developing the first version of the Procurement Metamodel (PMM 1.0)

The internal design cycle is the heart of any design science research project. This cycle of research activities iterates between constructing an artefact, its evaluation, and subsequent feedback to further refine the design. The tailored method which is drawn from the rigor cycle is used in this phase to develop and implement the metamodel. As indicated in the process, this method is based on gathering as many guidelines as possible and combining them to achieve a complete metamodel. This is what all the metamodelling processes are relied upon. However, care should be taken where the guidelines have overlapping incompatible parts, so a proper strategy has to be used to prevent the incompatibilities effecting the integrity of the metamodel. So, step 5 is where the finalized tuples are created and consists of 5 sub steps in which the concepts are filtered according to their occurrence. Also, the knowledge sources (gathered guidelines) are weighted, so in the case of incompatibility between two sources the tuple with the higher source will be nominated to be used in the metamodel. The development steps are as follows.

Step 1: Knowledge gathering: The PPP guidelines and frameworks are collected from the infrastructure departments of different countries, regulatory agencies, consultancy agencies and PPP expert groups from all around the world.

Step 2: Creating the domain breakdown structure: the PPP domain consists of a variety of phases and several steps in each phase which makes it a very wide domain. So before extracting the meaningful information pieces from the PPP guidelines, a structure for breaking down the domain must be created to ensure that the information extracted is organised and focused. The domain structure is developed based on the structure of guidelines and is shown in chapter 4.

Step 3: Identifying the development and verification sets: the guidelines should be divided into two sets where one can be used to develop the metamodel and the other for the first
round of metamodel verification. The sets should be selected such that the guidelines of each set cover every metamodel viewpoint.

**Step 4: Extraction of concepts:** the guidelines are published in a textual format accompanied by charts and figures. In order to have uniform information, the extracted statements from every guideline are transformed into a tuple format (concept – relationship – concept).

**Step 5: Creating the finalised tuples:** in this step the finalised concepts and relationships are used to create the finalised tuples which constitute the body of a viewpoint (a fragment of the metamodel);

**Step 6: Identifying the relationships to other viewpoints:** when defining the finalised tuples of each viewpoint, some concepts will have been defined in previous viewpoints, so they can be reused in the viewpoint and the common concept will relate the two viewpoints together. At the end of defining each viewpoint, every concept is checked to see whether it has any relationship to the concepts of other viewpoints.

The development of the metamodel is provided in the first section of chapter 4.

### 3.4 Validation of PMM 1.0 and Developing PMM 1.1

Juhani [161] states, “The essence of Information Systems research as design science lies in the scientific evaluation of artefacts.” Artefacts must be rigorously and thoroughly tested in laboratory and experimental situations before releasing them for field testing along the relevance cycle. This calls for multiple iterations of the design cycle in design science research before contributions are output into the relevance and rigor cycles.

A variety of techniques for evaluating metamodels are reviewed and described in 2.6.4. In this study a mixture of techniques is used to ensure that the metamodel is evaluated from several aspects and based on a variety of metrics. The first validation used in this study is to compare the metamodel against the guidelines of validation set. This validation technique ensures the metamodel is complete by identifying and adding any missing concepts.

In order to evaluate the metamodel, it is iteratively compared against other PPP guidelines which are not used in its development. Figure 3-4 shows that the metamodel is located at the M2 layer because it means to be a generic model of the PPP domain that will be used as the abstract syntax of a PML which the users (modellers) use to generate project models (user
models) at M1. The PPP guidelines are published by the government bodies, (mostly departments and ministries of Finance, Treasury and Infrastructure); whose names suggest they are developed to guide and regulate the practitioners to follow the PPP processes and prepare the required documents. The guidelines contain generic information about PPP processes and provide generic guidance on conducting the processes and developing the required documents, i.e. they are independent of any specific project so the guidelines are located at the M2 layer. The steps of this phase are as follows, and the second part of chapter 4 describes these steps.

1. Extraction of tuples from the validation set guidelines
2. Mapping extracted tuples to the metamodel tuples
3. Identifying new concepts for the metamodel
4. Creating new generalised concepts
5. Identifying the relationships of new concepts to the existing concepts

The validation of PMM 1.0 and creation of PMM 1.1 are described in the second part of chapter 4.

3.5 Developing the Procurement Modelling Language (PML)

The relevance cycle not only identifies the research problem and requirements as inputs, it also defines acceptance criteria for the ultimate evaluation of the research results. The output from the design science research must be returned to the environment for study and evaluation in the application domain. In order to make the metamodel applicable, it must be implemented in a tool to allow practitioners to use it for modelling the procurement projects. The following are the steps of this sub-phase:

**Step 1: Linking the PMM to UPDM:** the developed and verified metamodel is linked to the UPDM metamodel using the method provided by Selic [142].

**Step 2: Implementing the metamodel by stereotypes:** the stereotypes are specialised classes with specific attributes which represent the concepts and relationships of the metamodel. In this step the metamodel elements are implemented in the modelling tool.

**Step 3: Writing the language rules in Java:** the rules and constraints of the domain which is identified in creating the metamodel are written in Java language, so they enforce the rules to the metamodel to ensure the generated models are consistent and well formed.
Step 4: Developing the customised new diagram frames: every viewpoint of the metamodel represents a type of diagram so in this step a diagram frame is created for each viewpoint to allow the modellers to generate a piece of the project model. The frames are similar to UML and SysML diagrams (class diagram, activity diagram, etc.) but they are domain specific because they are designed specifically for the PPP domain.

Step 5: Developing the process guide: in this step the right order of using the diagrams is provided to the users as a modelling process guide.

The first part of Chapter 5 explains how the metamodel is implemented as a profile in the Magic Draw tool.

3.6 Benchmarking the PML versions against UML versions

In this round the verification technique provided by Ma et al [150] is used to analyse and assess the internal characteristics of the metamodel. The steps are as follows:

Step 1: calculating the basic parameters: the 6 basic parameters (Modelling concept size, Hierarchy, Coupling, Intension, Inheritance and Abstract metaclass size) are calculated according to the metrics defined in Table 3-2.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOH</td>
<td>This metric value is the number of metaclass inheritance hierarchies in a metamodel</td>
</tr>
<tr>
<td>ADI</td>
<td>This metric value signifies the average depth number of metaclass inheritance hierarchies in a metamodel</td>
</tr>
<tr>
<td>ANA</td>
<td>This metric value signifies the average number of metaclass from which a metaclass directly inherits</td>
</tr>
<tr>
<td>ANDM</td>
<td>This metric value signifies the average number of metaclass with which a metaclass directly associates</td>
</tr>
<tr>
<td>ANM</td>
<td>This metric value signifies the average number of metaattributes of a metaclass</td>
</tr>
<tr>
<td>ANMC</td>
<td>This metric value signifies the average number of metacombinations of a metaclass</td>
</tr>
<tr>
<td>ANR</td>
<td>This metric value signifies the average number of well-formed rules of a metaclass</td>
</tr>
<tr>
<td>NAM</td>
<td>This metric value is the number of abstract metaclasses in a metamodel</td>
</tr>
<tr>
<td>NCM</td>
<td>This metric value is the number of concrete metaclasses in a metamodel</td>
</tr>
</tbody>
</table>

1. Modelling concept size = NCM
2. Hierarchy = NOH
3. Coupling = ANDM + ANA
4. Intension = ANM + ANR + ANMC
5. Inheritance = ADI
6. Abstract metaclass size = NAM

**Step 2: Normalisation of parameters:** Because the values of some quality parameters (e.g., modelling concept size) are larger and some (e.g., Intension) are smaller, the larger values will result in an unfair influence on the results calculated from the above equations. Hence, we need to normalize the calculated values of the basic parameters. Depending on the calculated values a proper normalization formula has to be selected for normalisation.

**Step 3: Calculating the quality properties:** the main quality properties used to indicate the assessment results are calculated according to the following formulae:

- **Reusability** = $-0.3 \times \text{coupling} + 0.8 \times \text{intension} + 0.3 \times (\text{modelling concept size} + \text{abstract metaclass size})$
- **Understandability** = $-0.2 \times \text{coupling} + 0.7 \times \text{intension} - 0.1 \times \text{inheritance} - 0.1 \times (\text{modelling concept size} + \text{abstract metaclass size}) - 0.2 \times \text{hierarchy}$
- **Functionality** = $0.4 \times \text{coupling} + 0.4 \times \text{intension} + 0.2 \times \text{modelling concept size}$
- **Extendibility** = $-0.2 \times \text{coupling} + 0.3 \times (\text{modelling concept size} + \text{abstract metaclass size})$
- **Well-structured** = $-0.2 \times \text{coupling} + 0.8 \times \text{intension} - 0.1 \times \text{hierarchy}$

**Step 4: interpreting the results:** Since the quality properties are relative, they should be compared to UML versions so the quality of the metamodel can be discussed.

The second part of chapter 5 explains this benchmarking.

### 3.7 Application and Demonstration of the PML

As mentioned in the design science cycles, Figure 3-2) the created artefact must be applied in the domain of application to assess its usability, so to apply the language in the real domain, some real PPP project documents must first be collected. Projects are collected from different countries and different sectors to
ensure the metamodel is assessed over quite a large variety of application domains. Since the project documentation is confidential intellectual property the complete documentation of a project is unlikely to be found even if the documents are partially available, so the other criterion for collecting project documents is to ensure they aggregately cover all the metamodel viewpoints. Chapter 6 demonstrates the application of language for modelling real projects.
4. Chapter 4: Development and Validation of the Procurement Metamodel (PMM)

“Every block of stone has a statue inside it and it is the task of the sculptor to discover it”

(Michelangelo Buonarroti)

As mentioned earlier, the procurement of infrastructure systems is a wide and complex domain because documents generated during the lifecycle of project are prone to inconsistency and incompleteness due to the amount of interdependencies between the project artefacts such that any change in a document may lead to changes in other related documents. Moreover, there are a large number of stakeholders in this domain, each of which has personal concerns about the project and therefore generates information related to and consistent with the information generated by other stakeholders. For example, project lenders are concerned with project costs and whether the revenue generated will cover them, and the level of risk transferred to the private sector. These estimated costs, revenue, and risk allocations are drafted by the public sector (procurement agency) and then revised by the bidders during the tendering process. Although this information is confidential, project lenders need access to them to decide how much debt they can provide to the project company.

Although a variety of procurement management approaches have been developed to facilitate documentation, they cannot overcome the complex procurement described in the literature review, which is why the procurement guidelines are complex and then difficult to follow and apply. Moreover, each guideline only partially covers the domain so there is no complete guideline that covers the whole domain, so the guidelines are specific to a sector or a country and are therefore not directly applicable to other sectors or countries. The main objective of this research is to develop a metamodel for the procurement domain which will overcome the procurement challenges of incompleteness and inconsistency. This metamodel identifies the main procurement concepts and their relationships by extracting them from different guidelines and standards. As mentioned, each guideline is not usually complete on its own, but combinations of them will create a complete metamodel of the domain. As the guidelines
are introduced by different countries they may not be compatible to each other, so combining them without considering any precautions may lead to an inconsistent metamodel. Therefore, in one of the main steps of metamodel development (creating the finalized tuples) there are 5 sub-steps that carefully pick the concepts according to their importance (occurrence) which assures finding the right relationship between them. The knowledge sources also have an importance factor, so once it comes to an inconsistency between two sources, the tuple taken from the source with more weight overrules the weaker tuple. It should also be mentioned that the metamodel is meant to be kept brief, so as mentioned, only the more important concepts are used in creating the metamodel. This metamodel can work in conjunction with other modelling languages and frameworks (SysML and UPDM) in the same modelling environment, so if the metamodel was missing a concept in modelling a construct, then SysML blocks or other elements can be used to create the missing concept and develop the model.

The metamodel allows creating the well-formed models that are integrated and complete to be generated. So although every stakeholder generates some information and accesses some other information, the consistency of the project models is assured because they are produced by ‘one’ integrated metamodel which plays the role of an abstract syntax of the procurement domain, while needing to be mapped to a concrete syntax as a user interface which allows modeller/user to use the metamodel to produce procurement models. This concrete syntax is implemented using a UML profile. This metamodel and its implementation creates a modelling language which is called the Procurement Modelling Language (PML) in this thesis.

4.1 Developing the Procurement Metamodel (PMM)

The previous chapter explained how a variety of methods are adapted to tailor a customised process for developing the objective artefacts of this research. The first part of this chapter uses that process to develop the metamodel while the second part validates the metamodel to improve its completeness. The next chapter describes the development of the metamodel as a UML profile in a UML tool.

The steps used to develop the metamodel are as follows, and are explained using examples in the sections below.

1. Knowledge gathering
2. Domain structure and viewpoint identification
3. Selecting the development and validation sets
4. Concept extraction
5. Create the finalised tuples of viewpoints
6. Viewpoints inter-relationships

4.1.1 Knowledge Gathering

According to Strembeck [138] and as elaborated in the literature review chapter (2.6.3), there are different ways to identify the metamodel elements, each of which requires a different type of knowledge to be collected as the creation material. In a bottom up approach the sources of knowledge are the domain instances, which means gathering as many instances as possible, identifying their common features and thus identify the metamodel elements (abstract model).

In the top down approach, instead of collecting and generalising instances, the metamodel elements are extracted directly from the sources of knowledge. In this approach these sources must be the generic knowledge about the domain and should be independent of any specific instance; that is, the sources should contain typical information which can be instantiated to generate the instances.

This research uses the top down approach for three reasons: firstly, the procurement domain instances are confidential contracts with very limited access. Secondly, even if the contracts are accessible, they are very large which means analysis takes a long time or it is impossible. The third reason is that many situations and states may appear in a contract so only collecting a limited number means that all those situations could not be identified. This research therefore uses a top down approach and must identify the sources that contain typical information about the procurement domain. The procurement guidelines or frameworks published by procurement agencies and government authorities are the best materials for this research because they contain the information needed to produce the contracts (domain instances); this information can therefore help to identify the metamodel (abstract model or abstract syntax) elements.

In order to collect PPP procurement guidelines, the department of finance, the department of infrastructure and their equivalent department or ministries of those countries that practice PPP procurement were searched, however, only those resources written in English were used. Guidelines can also be identified by those materials that guide through finding the appropriate guidelines. There are two resources that introduce suitable guidelines for every
section of the procurement domain (procurement sections are known as viewpoints in this research), EPEC Guide to Guidance [69] and World Bank PPP reference guide [84]. These two documents have a breakdown structure of the PPP domain and introduce a variety of guidelines for every section, so they were collected for this study.

Appendix 8.1 shows the full list of guidelines used, including the country or agency where they were published. Since there is no standard structure for the PPP domain and every country and agency provides its own PPP structure, as the first step of domain standardisation, a unified PPP structure is created in the next section.

4.1.2 Domain Structuring and Viewpoint Identification

PPP guidelines generally have a phase based structure where the procurement life cycle is divided into phases and each phase is divided into steps; and despite having similar structures, there is no unified structure for the PPP domain. As discussed in 3.1.3 (Tailoring a DSL development process to the project’s context), according to the ISO/IEC/IEEE 42010:2011 [117] and COMPASS AF development guide [45], the first step in developing a metamodel for a complex domain is to identify the sections and then create a metamodel piece (viewpoint) for each section; this approach is also known as divide and conquer strategy. Moreover, a unified breakdown structure means the guidelines can be combined by mapping their corresponding sections to each other, and since the aim here is to use the knowledge of different guidelines to create a unified metamodel, a standardised domain breakdown must be produced.

To identify the main procurement viewpoints, the structure of some selected guidelines are analysed and recorded in uniform tables; the guidelines used for this step are those that completely cover the domain and indicate its structure in an organised format. Every country may have more than one guideline, so the main guidelines from each country are selected, and the guidelines of main agencies such as PPIAF, EPEC and World Bank are also used. The structure of the selected PPP guidelines are extracted and shown in Appendix 8.2 (Table 8-2 to Table 8-8).

Those PPP phases and steps in the analysed frameworks that are frequently repeated also help to create the domain structure and identify the viewpoints. Table 4-1 indicates the 15 viewpoints which completely cover the PPP domain; according to ISO/IEC/IEEE 42010 each viewpoint is created to address a set of concerns; the list of viewpoints and their corresponding concerns is provided in Table 4-2.
Table 4-1: Procurement Domain Viewpoints

<table>
<thead>
<tr>
<th>VP no.</th>
<th>Viewpoint name</th>
<th>VP no.</th>
<th>Viewpoint name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PPP Functions and Roles</td>
<td>9</td>
<td>Output Services</td>
</tr>
<tr>
<td>2</td>
<td>Financing Structure</td>
<td>10</td>
<td>Payment Mechanism</td>
</tr>
<tr>
<td>3</td>
<td>Project Costs</td>
<td>11</td>
<td>Dispute Resolution Mechanism</td>
</tr>
<tr>
<td>4</td>
<td>Project Risks</td>
<td>12</td>
<td>Contract Termination Management</td>
</tr>
<tr>
<td>5</td>
<td>Risk Assessment and Management</td>
<td>13</td>
<td>Request for Proposal and Proposal</td>
</tr>
<tr>
<td>6</td>
<td>Feasibility Assessment</td>
<td>14</td>
<td>Bid Evaluation</td>
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<td>7</td>
<td>Financial Assessment</td>
<td>15</td>
<td>Contract Management</td>
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<tr>
<td>8</td>
<td>Value for Money Assessment</td>
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<td></td>
</tr>
</tbody>
</table>

Table 4-2: Domain Viewpoints and their corresponding Concerns

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PPP Functions and Roles</td>
<td>What organisations are involved and what are their roles in this project?</td>
</tr>
<tr>
<td>2 Financing Structure</td>
<td>What are the finance sources for covering the project costs?</td>
</tr>
<tr>
<td></td>
<td>How much are the overhead costs of finance?</td>
</tr>
<tr>
<td>3 Project Costs</td>
<td>What costs are associated with the whole of life of the project?</td>
</tr>
<tr>
<td>4 Project Risks</td>
<td>What are the risks and uncertainties involved in this project?</td>
</tr>
<tr>
<td>5 Risk Assessment and Management</td>
<td>How much is the fiscal cost of each risk?</td>
</tr>
<tr>
<td></td>
<td>How are the risks managed?</td>
</tr>
<tr>
<td>6 Feasibility Assessment</td>
<td>Are there obstacles which make the project unfeasible?</td>
</tr>
<tr>
<td>7 Financial Assessment</td>
<td>Is the project economically and commercially viable?</td>
</tr>
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<td></td>
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<td>---</td>
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<tr>
<td>8</td>
<td>Value for Money Assessment</td>
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<tr>
<td>9</td>
<td>Output Services</td>
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<tr>
<td>10</td>
<td>Payment Mechanism</td>
</tr>
<tr>
<td>11</td>
<td>Dispute Resolution Mechanism</td>
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<tr>
<td>12</td>
<td>Contract Termination Management</td>
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<tr>
<td>13</td>
<td>Request for Proposal and Proposal</td>
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<tr>
<td>14</td>
<td>Bid Evaluation</td>
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<tr>
<td>15</td>
<td>Contract Management</td>
</tr>
</tbody>
</table>

### 4.1.3 Selecting the Development and Validation Sets

As mentioned in the methodology chapter, the developed metamodel and UML profile will be validated by a variety of techniques; the first of which improves the completeness of the metamodel and is based on comparing the metamodel to other guidelines. In this method the domain knowledge is divided into two sets, one to develop (development set) and the other to validate (Validation set) the metamodel. To divide the guidelines into these two sets the following criteria are applied:

- The development and validation sets shall contain The National and Global guidelines.
• Every viewpoint must be developed by at least 4 guidelines selected from the National and Global guidelines.
• Each viewpoint should be validated against at least 2 guidelines selected from the National and Global guidelines.
• The sector specific (Water, Roads and Highway, Transport) guidelines should be categorised in the validation set.
• If a guideline contributes 3 viewpoints or less and those viewpoints are covered by enough guidelines, that guideline will be removed; 13 guidelines were removed in this step.

Using the criteria provided, the guidelines are separated into two sets as indicated and ordered alphabetically in Table 4-3. The full list of guidelines is available in Appendix 8.1.

<table>
<thead>
<tr>
<th>Source no.</th>
<th>Scope</th>
<th>Sector</th>
<th>Source name</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2</td>
<td>World Bank</td>
<td>Generic</td>
<td>How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets [162]</td>
</tr>
<tr>
<td>D3</td>
<td>PPIAF</td>
<td>Generic</td>
<td>Numerical simulation model for Highways - PPP projects [163]</td>
</tr>
<tr>
<td>D4</td>
<td>World Bank</td>
<td>Generic</td>
<td>Concessions for infrastructure - A guide to their design and award [164]</td>
</tr>
<tr>
<td>D5</td>
<td>ESCAP</td>
<td>Generic</td>
<td>A Guidebook on Public Private Partnerships in Infrastructure [165]</td>
</tr>
<tr>
<td>D6</td>
<td>OECD</td>
<td>Generic</td>
<td>Public Private Partnerships - In Pursuit of Risk Sharing and Value for Money [166]</td>
</tr>
<tr>
<td>D7</td>
<td>World Bank</td>
<td>Generic</td>
<td>Government Guarantees - Allocating and Valuing Risk in Privately Financed Infrastructure Projects [167]</td>
</tr>
<tr>
<td>D8</td>
<td>European Commission</td>
<td>Generic</td>
<td>Guidelines for Successful Public-Private-Partnerships [168]</td>
</tr>
<tr>
<td>D10</td>
<td>Australia</td>
<td>Generic</td>
<td>National PPP Guidelines Volume 2: Practitioners' Guide [170]</td>
</tr>
<tr>
<td>D11</td>
<td>Australia</td>
<td>Generic</td>
<td>National PPP Guidelines Volume 4: Public Sector Comparator Guidance [171]</td>
</tr>
<tr>
<td></td>
<td>Country</td>
<td>Region</td>
<td>Document Type</td>
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<tr>
<td>D12</td>
<td>QLD, Australia</td>
<td>Generic</td>
<td>Public private partnerships guidance material, Supporting document</td>
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<tr>
<td>D13</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 4: PPP Feasibility Study</td>
</tr>
<tr>
<td>D14</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 5: PPP Procurement</td>
</tr>
<tr>
<td>D15</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 6: Managing the PPP Agreements</td>
</tr>
<tr>
<td>D16</td>
<td>UK</td>
<td>Generic</td>
<td>Standardisation of PF2 Contracts, HM Treasury</td>
</tr>
<tr>
<td>D17</td>
<td>UK</td>
<td>Generic</td>
<td>Standardisation of PFI Contracts, HM Treasury, Version 4</td>
</tr>
</tbody>
</table>

**Validation Set**

| V1  | PPIAF | Roads and Highways | The Toolkit for Public-Private Partnerships in Roads and Highways [34] |
| V2  | EPEC  | Generic            | The European PPP Expertise Centre (EPEC), PPP Guide [69] |
| V3  | World Bank, PPIAF | Water Services | Approaches to Private Participation in Water Services, A TOOLKIT [179] |
| V4  | Asian Development Bank | Generic | Public-Private Partnership Handbook [70] |
| V5  | India | Generic            | Public Private Partnerships in India: toolkit [35] |
| V6  | India | Transport          | VFM-Indicator-tool [180] |
| V7  | Hong Kong | Generic | An Introductory Guide to Public Private Partnerships (PPPs) [181] |
| V8  | Hong Kong | Generic | Practical Guide to Public Private Partnership (PPP) Projects [182] |
| V9  | India | Bus Transport      | Toolkit for public Private Partnerships in Urban Bus Transport [183] |

### 4.1.4 Concept Extraction

Once the development and validation sets are identified, the former set is used to create the metamodel. The development set guidelines and the viewpoints they contribute are shown in Table 4-4. The numbers written in each cell indicate the page number of the guideline from which the concepts are extracted.
As discussed earlier, the guidelines are in document format and are structured differently, so the first step towards combining the guidelines is to create a unified structure for the domain which enables us to look at each guideline from the defined viewpoints. Since the knowledge

<table>
<thead>
<tr>
<th></th>
<th>VP 1</th>
<th>VP 2</th>
<th>VP 3</th>
<th>VP 4</th>
<th>VP 5</th>
<th>VP 6</th>
<th>VP 7</th>
<th>VP 8</th>
<th>VP 9</th>
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Table 4-4: Development set guidelines vs Viewpoints
sources are document based materials it is impossible to extract the concepts from the text without any extraction technique because every section (viewpoint) of a document contains many pages of text (thousands of words) and every word can potentially be a useful concept. This means an extraction technique is needed to collect the concepts from the guidelines in a uniform and consistent way.

As Table 4-2 shows, every viewpoint is mapped to a set of concerns, which means that the viewpoint (metamodel piece) generates part of the user model which contains the information which addresses that concern. In the other words, the elements of the user model are directly related to a concern and therefore the viewpoint elements should be related to a meta-concern. As Figure 4-1 shows (see also Figure 2-10), since a metamodel is a generalised form of the user model, the concern can be generalised to create a meta-concern which can then be used to identify the metamodel concepts. According to this rationale, each concern is generalised to create a statement which can be used as the “concept extraction question” which then allows us to extract the required concepts from the guidelines; in other words, the extracted concepts are the answer to the defined question.

**Figure 4-1: Creating the meta-concern as the concept extraction question**

For example, the “Project Risks” view of the user model addresses this concern: “What are the risks and uncertainties involved in this project”? The generalised version of this statement will be: “What are the typical risks and uncertainties involved in a typical infrastructure project”? So, in order to extract the concepts for the Project Risks viewpoint, we looked for the answer in the guidelines and the found the answer recorded as the extracted concepts from that guideline for that viewpoint. As described in 4.1.1 (Knowledge Gathering) the sources of knowledge must be in the right level of abstraction so they would contain the answers to typical questions. Since the guidelines are independent of any project and provide information about typical projects, they are suitable sources for finding the answers to
questions about concept extraction. The list of concerns and their respective Concept Extraction Questions is provided in Table 4-5.

Table 4-5: Viewpoints and their Concept Extraction Questions

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Concept Extraction Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPP Functions and Roles</td>
<td>What typical organisations can be involved in a project?</td>
</tr>
<tr>
<td></td>
<td>What are the typical roles of those organisations?</td>
</tr>
<tr>
<td>Financing Structure</td>
<td>What are the possible financing methods in a project?</td>
</tr>
<tr>
<td></td>
<td>What concepts help to calculate the cost of finance?</td>
</tr>
<tr>
<td>Project Costs</td>
<td>What are typical whole-of-life costs of a project?</td>
</tr>
<tr>
<td>Project Risks</td>
<td>What are the typical risks and uncertainties involved in a typical infrastructure project?</td>
</tr>
<tr>
<td>Risk Assessment and Management</td>
<td>What attributes are required to assess and prioritise a typical risk?</td>
</tr>
<tr>
<td></td>
<td>What are the typical methods of risk management?</td>
</tr>
<tr>
<td>Feasibility Assessment</td>
<td>What aspects must be considered in assessing project feasibility?</td>
</tr>
<tr>
<td>Financial Assessment</td>
<td>What financial aspects must be assessed to determine the financial viability of a project?</td>
</tr>
<tr>
<td>Value for Money Assessment</td>
<td>What factors contribute to assessing the project in terms of value for money?</td>
</tr>
<tr>
<td></td>
<td>How should those factors be calculated?</td>
</tr>
<tr>
<td>Output Services</td>
<td>How are the output services specified in a contract?</td>
</tr>
<tr>
<td></td>
<td>What are the important aspects in writing the output services part of a contract?</td>
</tr>
</tbody>
</table>
| Payment Mechanism                  | What are the typical mechanisms by which a private party can be paid?  
|                                  | Or, what are the typical sources that generate revenue cash flow?     |
| Dispute Resolution Mechanism     | How should a dispute resolution mechanism be planned in a contract?    |
| Contract Termination Management  | What aspects should be considered in writing the contract termination plan? |
| Request for Proposal and Proposal| What are the typical elements of the Request for Proposal and Proposal documents? |
| Bid Evaluation                   | What aspects should be considered in evaluating and comparing the bids? |
| Contract Management              | How should the contract management plan of a contract be developed?    |

Extracting answers from the guidelines is a manual task that is carried out by reading the guidelines to find the answer. These extracted answers are recorded according to the format of the answer; it can for instance be a list of concepts where the answer is a list of items e.g. Typical Project Risks and Typical Project Costs. When the relationship between the concepts is important, the answers are recorded as a tuple (concept – relationship – concept); for example the concepts extracted from the Singapore PPP guidelines for the “Payment Mechanism” viewpoint includes “Unitary Payment --is based on -- Unit of Service; Service -- measured by -- unit of measure; Service -- comply with -- performance standards”. The answers can be a formula, which is another form of tuple; this can be exemplified by the answers extracted from the South African PPP guidelines for the “Risk Assessment and Management” viewpoint, which includes these formulae:

“Impact of Risk ($) = Effect on PSC Base Cost (consequence Severity) (%) * exposure Cost ($) ;  
Risk Value ($) = Impact of Risk ($) * Likelihood (%) ;
Total Risk Value = \( \text{Sum (Risk Value of each Risk State)} \);’’

The total number of concepts extracted in this step is estimated to be around 4000; the concepts extracted from each guideline for each viewpoint are provided in Appendix 8.3.

4.1.5 Create the Finalised Tuples of Viewpoints

Once the concepts have been extracted from the knowledge sources for every viewpoint, the viewpoints can be created using the collected concepts. Note that the viewpoints are not created yet at this stage, but we know their names and the concerns they address, so we extract the concepts to construct the viewpoints. As mentioned earlier, since the knowledge sources are at the same level of abstraction (M2) as the metamodel, the collected concepts do not need to be generalised, they can directly contribute to constituting the metamodel elements. However, although all the extracted concepts can help to create the viewpoints’ tuples, to ensure the conciseness and genericity of the metamodel, they should be filtered using a consistent method. As will be described in the metamodel validation section, the conciseness of the metamodel cannot be evaluated due to insufficient sources, so this filter is applied to ensure metamodel conciseness in the development phase rather than the validation phase.

According to this explanation, a mechanism is needed to select the nominated concepts and create finalised tuples of each viewpoint. As described in the Methodology chapter, the method used by Caro et. al [140] to develop a metamodel to support cognition, which is adapted from Beydoun et. al [139] and Othman et. al [141], is used in this part of the development process, so the concepts are reviewed and defined as follows:

1. Filtering by occurrence: The number of sources in which each concept appears is counted, and then the concepts that appear in at least half the guidelines (2 out of 4 or 3 out of 5, etc.) are selected as candidates to be included in the viewpoint. Moreover, the remaining concepts are marked as “pending” for the validation process, and are shown in italic format in the concept tables. If the concept appears frequently enough in other guidelines in the validation process, then the concept will be considered as a candidate for inclusion in the viewpoint; this step means that only those concepts are important in the domain, albeit it endangers the completeness of the metamodel.

As mentioned before, the first validation technique makes the metamodel more complete by considering the concepts of other guidelines. Moreover, changing the filter threshold leads to
changing the number of metamodel concepts; for example, if the occurrence filter is set to select the concepts with 30% of occurrence (instead of 50%) the number of metamodel concepts would grow and lead to a larger metamodel which is more complete but less concise. The current threshold is set at 50% because it generates a metamodel with 100 to 150 concepts, which is the size of metamodels in similar studies. The discussion about setting a threshold that balances between completeness and conciseness is left for the future studies in this research.

(2) Concept unification: If two or more concepts have similar meanings then the concept with more occurrences or the one suggested by more generic guidelines (World bank and PPIAF guidelines are ranked higher than continent wide ones e.g. European Commission, and in turn they are ranked higher than national guidelines), or the one whose definition is more consistent with the rest of the concepts, will be selected for inclusion in the metamodel while the others will be discarded, for example: EnvironmentalPolicy, EnvironmentalStandard and EnvironmentalLegislation are mentioned in World Bank, PPIAF and South Africa guidelines, respectively. So the EnvironmentalStandard is included in the metamodel and the other two are excluded because the EnvironmentalStandard is mentioned in PPIAF and this concept is a type of RegulatoryStandard. This step generates 176 finalised concepts which create the metamodel. Furthermore, each viewpoint is also counted as a concept so the number 176 includes the number of viewpoints (which is 15).

(3) Concept Reclassification: The concepts extracted for a viewpoint are often related to other viewpoints or are seen in the other viewpoints, in which case the concepts are moved to the viewpoint list because it is better suited to keeping those concepts. For example, RiskMonitoring, RiskManagementStrategy and DisasterResponse are extracted from the ‘Contract Management’ viewpoint but then moved to ‘Risk Assessment and Management’ because they are related more to this viewpoint. The other example is ServiceTimePeriod which is moved from the ‘Payment Mechanism’ viewpoint to the ‘Output Services’ viewpoint. The output of this step is a list of finalised concepts for each viewpoint, as indicated in Table 4-6. Note that the number of concepts is 176, but a concept often appears in more than one viewpoint; the table shows all the concepts used in each viewpoint, so the concepts may be seen more than once.

(4) Definition of concepts: like the method of concept unification, the definition of each concept is taken from a source which is more generic and consistent with the definition of other concepts. The definitions of the concepts are provided in Appendix 8.5.
(5) Concept Relationships: as mentioned, the concept relationships were extracted with the concepts (as tuples), but once the concepts are finalised the relationships between them are created based on what is extracted in the tuples. The output of this phase is the conceptual definition of viewpoints that are shown graphically in Appendix 8.4.

### Table 4-6: Finalized Concepts of Viewpoints

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Finalized concepts</th>
</tr>
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<tbody>
<tr>
<td>PPP Functions and Roles</td>
<td>PublicAuthority; PrivateParty; EngineeringOrganization; Operator; Financier; Shareholder; Lender; Finance; Operation; Maintenance; Design; Construction;</td>
</tr>
<tr>
<td>Financing Structure</td>
<td>ProjectFinance; Finance; Financier; CostOfFinance; Cost; Lender; Debt; Shareholder; Equity; CostOfDebt; ReturnOnEquity; InterestRate;</td>
</tr>
<tr>
<td>Project Costs</td>
<td>ProjectCosts; Cost; TimePeriod; YearlyAmount; Amount; Year; TotalAmount; NetPresentAmount; DiscountRate; OperationAndMaintenanceCost; CapitalCost; CostOfRisk; CostOfFinance; DirectOperationAndMaintenanceCost; WageAndSalaryCost; ManagementCost; OperationToolsAndEquipmentCost; InsuranceCost; OperationRawMaterialsCost; IndirectOperationAndMaintenanceCost; CapitalImprovementAndUpgradeCost; DirectCapitalCost; DesignCost; ConstructionCost; CapitalRawMaterialsCost; LandCost; ContractDevelopmentCost;</td>
</tr>
<tr>
<td>Project Risks</td>
<td>ProjectRisks; Risk; EconomicRisk; TechnicalRisk; TaxationRisk; InterestRateRisk; ExchangeRateRisk; CommercialRisk; FeeCollectionRisk; DemandRisk; ConstructionRisk; DesignAndConstructionQualityRisk; ConstructionCostOverrunRisk; ConstructionTimeOverrunRisk; OperationAndMaintenanceRisk; OperationCostOverrunRisk; InputSupplyRisk; AssetOwnershipRisk; AssetValueRisk; TechnologyObsolescenceRisk; ForceMajeure; EnvironmentalRisk; SocialRisk; RegulatoryAndPoliticalRisk;</td>
</tr>
<tr>
<td>Risk Assessment and Risk Management</td>
<td>Risk; RiskBaseCost; RiskMonitoring; RiskManagement;</td>
</tr>
<tr>
<td>Management</td>
<td>RiskManagementCost; RiskManagementStrategy; RiskMitigationStrategy; RiskTransferStrategy; DisasterResponseStrategy; TimePeriod; CostOfRisk; NetPresentAmount; YearlyAmount; Year; Amount; DiscountRate; RiskState; ConsequenceImpact; Probability; RiskStateCost;</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Feasibility Assessment</td>
<td>FeasibilityBarrier; TechnicalRisk; Technology; Asset; OutputService; RegulatoryStandard; StepInRight; GovernmentStepIn; EnvironmentalStandard; EnvironmentalRisk; SocialRisk; RiskAssessmentAndManagementViewpoint;</td>
</tr>
<tr>
<td>Financial Assessment</td>
<td>Bankability; Revenue; Debt; CostOfDebt; ServiceDemand; TransferredRisks; ProjectCosts; Equity; ReturnOnEquity; CommercialViability;</td>
</tr>
<tr>
<td>Value for Money Assessment</td>
<td>ValueForMoneyModel; PublicSectorComparator; PPPVFModel; TransferredRisks; RetainedRisks; Risk; RawPSC; RawCosts; ThirdPartyRevenue; BidPrice; CapitalCost; OperationAndMaintenanceCost;</td>
</tr>
<tr>
<td>Output Services</td>
<td>OutputService; TimePeriod; ServiceUnit; ServiceUnitPrice; ServiceRequirement; ServicePerformanceMonitoring; ServiceKPI; MonitoringCollectedData; MonitoringUnit; ManagementRole; ServicePerformanceFailure; SatisfactoryServicePerformance; PenaltyPayment; TerminationForPrivatePartyDefault; BonusPayment; ReportReceiver;</td>
</tr>
<tr>
<td>Payment Mechanism</td>
<td>Payment; Revenue; YearlyAmount; Year; Amount; UserCharges; ServiceDemand; Tariff; GovernmentPayment; UsageBasedPayment; AvailabilityBasedPayment; Subsidy; PenaltyPayment; BonusPayment; ServiceUnitPrice;</td>
</tr>
<tr>
<td>Dispute Resolution Mechanism</td>
<td>Dispute; DisputeResolutionMethod; DisputeResolutionCost; Court; Regulator; InternationalArbitrator; ExpertPanel; FinancialExpert; TechnicalExpert; PrivateParty; PublicAuthority;</td>
</tr>
<tr>
<td>Contract Termination</td>
<td>Termination; ScheduledTermination; ContractLength;</td>
</tr>
<tr>
<td>Management</td>
<td>LeastPresentValueOfRevenue; EarlyTermination; UnprofitableService; CompensationOnTermination; TerminationPayment; Payer; Payee; AssetHandover; AssetHandoverPayment; AssetQualityAssessment; Asset; AssetKPI; AssetValue;</td>
</tr>
<tr>
<td>Request for Proposal and Proposal</td>
<td>RequestForProposal; Proposal; PPPFunctionsAndRolesViewpoint; FinancingStructureViewpoint; ProjectCostsViewpoint; ProjectRisksViewpoint; RiskAssessmentAnd ManagementViewpoint; ValueForMoneyAssessmentViewpoint; OutputServicesViewpoint; PaymentMechanismViewpoint; DisputeResolutionViewpoint; ContractTerminationManagementViewpoint; ContractManagementViewpoint; ProjectTimeline; EvaluationCriteria; RegulatoryStandard; BiddingInstruction;</td>
</tr>
<tr>
<td>Bid Evaluation</td>
<td>EvaluationCriteria; CriteriaWeight; Proposal; ProposalRank; FinancialCriterion; NetPresentValueOfRevenue; Payment; ProjectCostsViewpoint; FinancingStructureViewpoint; PPPVFModel; TechnicalCriterion; DesignOption; OutputServicesViewpoint; ContractLength;</td>
</tr>
<tr>
<td>Contract Management</td>
<td>ManagementTask; ManagementRole; Skill; ManagementCost; RelationshipManagement; ChangeManagement; Adjustment; DisputeResolutionViewpoint; ContractTerminationManagementViewpoint; Monitoring; ContractComplianceMonitoring; ContractualIssue; ServicePerformanceMonitoring; RiskMonitoring; RiskManagement;</td>
</tr>
</tbody>
</table>

### 4.1.6 Viewpoints Inter-relationships

Due to the size and complexity of the domain, the metamodel was divided into viewpoints, each of which addressed a set of separate concerns. Despite this, a metamodel is one integrated artefact which addresses all the concerns in a consistent manner. As discussed earlier, the Architecture Frameworks (and metamodels) allow stakeholders to work in isolation and develop their own materials while the underlying metamodel maintains
consistency between the materials they generate; therefore, the linkage between the viewpoints should be identified so that they aggregately create the metamodel.

As shown in the Methodology (3.2.1), the development process is an iterative task whereby once every viewpoint is created its relationships to the previously related viewpoints is checked and identified. This means a metamodel is created incrementally by iterating their creation and relating the viewpoints; the following examples illustrate this part of the process.

‘PPP Functions and Roles’ viewpoint includes the Finance, Lender and Shareholder concepts which are also identified in the ‘Financial Structure’ viewpoint. The Debt, Equity, DebtInterest, EquirtRateOfReturn concepts are identified in the ‘Financial Structure’ and are seen later in the ‘Financial Assessment’ viewpoint. The most inclusive example is the ‘Request for Proposal and Proposal’ viewpoint because it reuses all the previously created viewpoints; that is, all the first 13 viewpoints are used to develop the materials which are written in the Request for Proposal (RFP) and are replied to by the Proposal. Note that although the RFP and Proposal are different documents in the real world, their abstract structure is at the metamodel level, which is why they do not have two different viewpoints. The outcome of this process is a full metamodel in which all the viewpoints are related to each other (through the relationships between their concepts).

4.2 Metamodel Validation

As discussed in the methodology chapter, the first technique for validating the PMM is comparing it to the validation set which contains guidelines that are not used in the development phase. This technique makes the metamodel even more complete; it was provided by Sargent [152] and adapted by Othman [141] to validate the Disaster Management Metamodel which is used in this study as the first validation method. A comparison was made to verify whether the tuples extracted from the validation guidelines could be represented by PMM, because if a key concept of some guideline could not be represented with PMM, then that concept is considered to be a candidate to be added to PMM. As Table 4-3 (Development and Validation sets) shows the set of validation guidelines are selected from a variety of scopes (global, continental and national) and different sectors (Generic, Water, Transport and Roads and Highways) to ensure the broadness of testing.

The validation steps are as below and are explained in the following sections:

1. Extraction of tuples from the set of validation guidelines
2. Mapping the extracted tuples to the metamodel tuples
3. Identifying the new concepts to be added to the metamodel
4. Creating new generalised concepts
5. Identifying the relationships of new concepts to the existing concepts

4.2.1 Extraction of the tuples from the validation set guidelines

The guidelines of the validation set, like the guidelines for the development set are large and in a text format without a standard structure. So, to compare the PMM to the validation guidelines the concept extraction method used for the development set is applied onto the validation set to have a structured and uniform set of data. This is why every guideline is questioned by the concept extraction questions of each viewpoint and the answer is recorded as the extracted tuples from that guideline for that viewpoint. The extracted tuples from the validation set are provided in Appendix 8.3. The number of concepts extracted in this step is estimated as 1700. To help compare the tables, the development and validation tuples of each viewpoint are provided together. As mentioned before, the guidelines partially cover the viewpoints, so not every viewpoint is covered by all the guidelines. The validation set and the viewpoints they cover are shown in Table 4-7.

<p>| Table 4-7: Validation set guidelines vs Viewpoints |</p>
<table>
<thead>
<tr>
<th>VP 1</th>
<th>VP 2</th>
<th>VP 3</th>
<th>VP 4</th>
<th>VP 5</th>
<th>VP 6</th>
<th>VP 7</th>
<th>VP 8</th>
<th>VP 9</th>
<th>VP 10</th>
<th>VP 11</th>
<th>VP 12</th>
<th>VP 13</th>
<th>VP 14</th>
<th>VP 15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>M5, p130</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39, 40</td>
<td>23</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>V3</td>
<td></td>
<td></td>
<td>90, 93</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75-77, 131</td>
<td>108-110</td>
<td></td>
<td>172, 173</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>V4</td>
<td></td>
<td></td>
<td>41</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5</td>
<td></td>
<td></td>
<td></td>
<td>M2-P2</td>
<td>M2-P2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>V6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Risk values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V7</td>
<td></td>
<td></td>
<td>15</td>
<td>110</td>
<td>58</td>
<td>110-115</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>V8</td>
<td></td>
<td></td>
<td>101</td>
<td>29</td>
<td>79</td>
<td>72</td>
<td>28</td>
<td>43, 85-92</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2.2 Mapping the extracted tuples to the metamodel tuples

Once the tuples have been extracted from the guidelines, the metamodel must be checked to determine whether it can accommodate all those tuples or not, so the concepts extracted for each viewpoint are compared against the corresponding tuples of the PMM viewpoint. The tuples or concepts which are not supported by the PMM tuples are recorded as nominated concepts to be added to the metamodel. For example, Table 4-8 shows the supported and unsupported tuples extracted from the Hong Kong PPP guideline, the World Bank Water Toolkit, and the PPIAF Highway Toolkit for the Financing structure viewpoint. The nominated concepts are shown in italic format in the concept tables.

Table 4-8: Comparing the Tuples of Validation Guidelines to the Financing Structure Viewpoint v1.0

<table>
<thead>
<tr>
<th>Source</th>
<th>Supported Concepts by the PMM</th>
<th>Unsupported concepts (Nominated for addition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects (p 101)</td>
<td>Subordinated Debt -- to -- SPV Shareholder funds or Equity -- to -- SPV Senior Debt -- to -- SPV</td>
<td>None</td>
</tr>
<tr>
<td>World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT (pp 90, 93)</td>
<td>Sources of Finance: Equity -- provided by -- (project promoter, Other investors) Loan -- provided by -- Local or Foreign Banks Export credit guarantee finance Loans -- provided by -- development agencies Grants -- provided by -- development agencies</td>
<td>Government -- provides -- (Equity, Loan); Government -- provides -- Government Finance;</td>
</tr>
<tr>
<td>PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways (Module 1, pp 55-58)</td>
<td>Equity investors: sponsors; passive investors; equity infrastructure funds; Commercial Lenders -- provide -- project finance</td>
<td>Commercial Lenders -- provide -- corporate finance; Project company -- provides -- guarantee</td>
</tr>
</tbody>
</table>

4.2.3 Identifying new concepts for addition to the metamodel
After identifying the unsupported concepts, their occurrence is checked to see whether they can be added to the PMM; which is why the pending concepts of the development stage (which were not used in the PMM due to their low occurrence) are counted together with the nominated concepts identified in the validation stage. The same occurrence rule used in the development stage is used to identify the new concepts, so if the occurrence of a concept found in the pending and nominated sets is at least half the total number of guidelines used to develop and validate that viewpoint then those concepts would be accepted for addition. Moreover, if a concept occurs three times in the pending and nominated sets it would be considered for addition, regardless of the total number of guidelines used for that viewpoint. Table 4-9 exemplifies the process of selecting the new concepts for addition to the PMM. This step identifies 48 new concepts to be added to the PMM. Table 4-10 indicates the new concepts added to each viewpoint.

Table 4-9: Selecting the new concepts for addition to the Financing Structure viewpoint

<table>
<thead>
<tr>
<th>Development Sources</th>
<th>Source</th>
<th>Pending Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>World Bank: Public-Private Partnerships Reference Guide, Version 2.0, (p 50)</td>
<td>to decrease the financial costs: Shareholder --- corporate guarantee --- lenders; Government --- corporate guarantee --- debt (lenders); Government --- provide finance (as lender) --- SPV</td>
</tr>
<tr>
<td></td>
<td>How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets, (p 53)</td>
<td>financial instruments (e.g. bonds); Lender -- provides -- corporate finance -- to -- Engineering contractor</td>
</tr>
<tr>
<td></td>
<td>A Guidebook on Public Private Partnerships in Infrastructure, ESCAP, (pp 40-45)</td>
<td>Debt -- has -- fixed maturity; Government -- Provides -- Grant</td>
</tr>
<tr>
<td></td>
<td>Numerical simulation model for Highways - PPP projects, (PPIAF) (section 3.4)</td>
<td>Investment Subsidy; Debt -- has -- interest rate -- grace period; Equity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Validation Sources</th>
<th>Source</th>
<th>Nominated Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects, (p 101)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>World Bank, PPIAF: Approaches to Private</td>
<td>Government -- provides -- (Equity, Loan); Government -- provides -- Government Finance;</td>
</tr>
<tr>
<td>Participation in Water Services, A TOOLKIT, (pp 90, 93)</td>
<td>Government -- provides -- Guarantee;</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------</td>
<td></td>
</tr>
<tr>
<td>PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways, (Module 1, pp 55-58)</td>
<td>Commercial Lenders -- provide -- corporate finance; Project company -- provides -- guarantee</td>
<td></td>
</tr>
</tbody>
</table>

**Concepts and tuples accepted for addition**

**New Concepts:**

CorporateFinance; CorporateGuarantee;

**New Tuples:**

(ReturnOnEquity, CostOfDebt, CorporateTax) -- contributes in -- WeightedAverageCostOfCapital;

Finance -- has type -- Corporate Finance;

Financier -- has -- FinancierDegreeOfCommitment;

PublicAuthority -- provides -- Debt

PublicAuthority -- provides -- CorporateGuarantee

Shareholder -- provides -- CorporateGuarantee

Debt -- has type -- CorporateFinance

Lender -- Provides -- CorporateFinance

Table 4-10: The new concepts added to each viewpoint of PMM

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>New concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPP Functions and Roles</td>
<td>Consumer; Consultant;</td>
</tr>
<tr>
<td>Financing Structure</td>
<td>CorporateFinance; CorporateGuarantee;</td>
</tr>
<tr>
<td>Project Costs</td>
<td>InsuranceCost;</td>
</tr>
<tr>
<td>Project Risks</td>
<td>DefaultOfPublicAuthority; DefaultOfPrivateParty;FinanceCostOverrunRisk;</td>
</tr>
<tr>
<td></td>
<td>InflationRateRisk; ChangeOfLawRisk;</td>
</tr>
<tr>
<td>Risk Assessment and Management</td>
<td>Insurance; RiskAcceptance; RiskAvoidance; RiskManagementCost</td>
</tr>
<tr>
<td>Feasibility Assessment</td>
<td>EnablingSystem; DesignOption;</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Financial Assessment</td>
<td>WeightedAverageCostOfCapital; CorporateTax;</td>
</tr>
<tr>
<td></td>
<td>ProjectInternalRateOfReturn;</td>
</tr>
<tr>
<td>Value for Money</td>
<td>CompetitiveNeutrality; PublicSectorAdvantage;</td>
</tr>
<tr>
<td>Assessment</td>
<td>PublicSectorDisadvantage; NominalDiscountRate; InflationRate</td>
</tr>
<tr>
<td>Output Services</td>
<td>UserFeedback; PerformanceBond;</td>
</tr>
<tr>
<td></td>
<td>ServiceImportanceLevel; FailureSeverityLevel;</td>
</tr>
<tr>
<td></td>
<td>CoreService; EnablingService; ExternalMonitor;</td>
</tr>
<tr>
<td>Payment Mechanism</td>
<td>ServicePriceAdjustment;</td>
</tr>
<tr>
<td>Dispute Resolution</td>
<td>Arbitration; DomesticArbitration;</td>
</tr>
<tr>
<td>Mechanism</td>
<td>MutualDiscussion; Mediation; SolutionToDispute;</td>
</tr>
<tr>
<td></td>
<td>ContractualIssue; DisputeResolutionCost;</td>
</tr>
<tr>
<td>Contract Termination</td>
<td>VoluntaryTermination;</td>
</tr>
<tr>
<td>Management</td>
<td></td>
</tr>
<tr>
<td>Request for Proposal</td>
<td>SiteSpecification; BidBond;</td>
</tr>
<tr>
<td>and Proposal</td>
<td></td>
</tr>
<tr>
<td>Bid Evaluation</td>
<td>ConcessionFee; FinancierDegreeOfCommitment</td>
</tr>
<tr>
<td>Contract Management</td>
<td>ServiceRequirementAdjustment; ConstructionMonitoring;</td>
</tr>
<tr>
<td>Monetary Items</td>
<td>MonetaryItem; Currency; ExchangeRate;</td>
</tr>
</tbody>
</table>

### 4.2.4 Creating new generalised concepts

The generalisation (or specialisation) relationships between the concepts is one of the most important relationships in all the metamodels because allows the attributes between the parent and child concepts to be inherited and it leads to a better structured metamodel by avoiding a repeat of attributes in different concepts. By following this rule, the structure of the metamodel can be improved by finding the common attributes of the concepts and creating generic concepts to accommodate the common properties. This task requires iterative parsing of the concepts and can be done at an arbitrary number of levels. Since there are many concepts in the PMM which are monetary elements, a new viewpoint called Monetary Items
is created to group the monetary concepts. The main concept of this viewpoint is MonetaryItem which accommodates all the money related attributes of the concepts and is defined as the parent of such concepts, e.g. Payment, Finance and Cost and obviously their sub-types e.g. GovernmentPayment, Debt and OperationAndMaintenanceCost. Creating this viewpoint means the common attributes from the children concepts can be deleted and moved to the MonetaryItem concept. The deleted properties can be seen by comparing v1.0 and v1.1 of the Project Costs Viewpoint (Figure 8-5 and Figure 8-6), Risk Assessment and Management Viewpoint (Figure 8-9 and Figure 8-10), Payment Mechanism Viewpoint (Figure 8-19 and Figure 8-20) and Contract Termination Management Viewpoint (Figure 8-23 and Figure 8-24). The Monetary Items Viewpoint is shown in Figure 4-2; it adds 4 new concepts to the metamodel (including the viewpoint itself, since each viewpoint is considered as a concept) which makes 48 added concepts. The total number of metamodel concepts is 224 after validation.

Net Present amount = \( \text{Sum} \left( \frac{\text{Yearly Value}}{(1+\text{Discount rate})^t} \right) \) for \( n \) years;  
or  
Net Present amount = \( \text{Sum} \left( \frac{\text{Yearly Value}}{(1+\text{Nominal Discount rate})^t} \right) \) for \( n \) years;  
Nominal discount rate = \( (1 + \text{real discount rate}) \times (1 + \text{inflation rate}) - 1; \)

Net Present Value (complex Item) = \( \text{Sum} \left( \text{Total Net Present amount (contained Items)} \right) \)  
Total amount (Complex Item) = \( \text{Sum} \left( \text{Total Amount (Contained Items)} \right) \)

Figure 4-2: Monetary Items Viewpoint

4.2.5 Identify the relationships between new and existing concepts
Once the new concepts for addition have been identified their relationship with the remaining concepts should be checked and added to the PMM. Like the development phase, the relationships are identified using the identified tuples; for example, the concept CorporateGuarantee can be added to the Financing Structure viewpoint. The extracted tuples Shareholder --- corporate guarantee --- lenders; Government --- corporate guarantee --- lenders; Government -- provides – Guarantee; Project company -- provides – guarantee; suggests that the CorporateGuarantee can be provided by the Government and the Project Company, so the following tuples are created to make the relationship between the concepts CorporateGuarantee, PublicAuthority and Shareholder:

- **PublicAuthority -- provides -- CorporateGuarantee**
- **Shareholder -- provides -- CorporateGuarantee**

The other example is identifying the RiskManagementCost and DisputeResolutionCost concepts in Risk Assessment and Management viewpoint and Dispute Resolution viewpoint, respectively. Since both of these concepts are a kind of ManagementCost they are connected to this concept through the following relationships:

- **ManagementCost -- has type -- DisputeResolutionCost;**
- **ManagementCost -- has type – RiskManagementCost;**

Table 4-11 shows the new tuples added to each viewpoint to maintain the relationship of the new concepts to other concepts.

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>New Tuples</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPP Functions and Roles</td>
<td>• Consultant -- consultation contract -- (Engineering organization; PublicAuthority;)</td>
</tr>
<tr>
<td></td>
<td>• Consumer -- pays for services -- (PublicAuthority; Privateparty;)</td>
</tr>
<tr>
<td>Financing Structure</td>
<td>• (ReturnOnEquity, CostOfDebt, CorporateTax) -- contributes in -- WeightedAverageCostOfCapital;</td>
</tr>
<tr>
<td></td>
<td>• Finance -- has type -- Corporate Finance;</td>
</tr>
<tr>
<td></td>
<td>• Financier – has – FinancierDegreeOfCommitment;</td>
</tr>
<tr>
<td>PublicAuthority -- provides – Debt;</td>
<td></td>
</tr>
<tr>
<td>PublicAuthority -- provides – CorporateGuarantee;</td>
<td></td>
</tr>
<tr>
<td>Shareholder -- provides – CorporateGuarantee;</td>
<td></td>
</tr>
<tr>
<td>Debt -- has type – CorporateFinance;</td>
<td></td>
</tr>
<tr>
<td>Lender -- Provides – CorporateFinance;</td>
<td></td>
</tr>
</tbody>
</table>

| Project Costs |
| ManagementCost -- has type -- (RiskManagementCost; DisputeResolutionCost;) |
| RiskManagementCost -- has type – InsuranceCost; |

| Project Risks |
| Risk – has type – (DefaultOfPublicAuthority; DefaultOfPrivateParty;FinanceCostOverrunRisk; InflationRateRisk; ChangeOfLawRisk;) |
| RegulatoryAndPoliticalRisk – has type – ChangeOfLawRisk; |
| EconomicRisk – has type – InflationRateRisk; |
| FinanceCostOverrunRisk -- has type -- InterestRateRisk; |

| Risk Assessment and Management |
| RiskManagementStrategy -- has type -- (RiskAvoidance; RiskAcceptance) |
| RiskTransfer --has type – Insurance; |

| Feasibility Assessment |
| OutputServices -- determine -- DesignOption; |
| OutputServices -- require -- EnablingSystems; |
| DesignOption -- determines -- Asset; |
| DesignOption -- constrained by -- RegulatoryStandard; |
| DesignOption -- constrained by -- Technology; |
| FeasibilityBarrier -- has type -- ProjectRisks; |

| Financial Assessment |
| (Equity, Debt, CostOfDebt, ReturnOnEquity, CorporateTax) -- contributes in -- WeightedAverageCostOfCapital; |
| (Revenue, ProjectCosts, Debt, Equity) -- contributes in -- ProjectInternalRateOfReturn; |
| (ProjectInternalRateOfReturn,
| **Value for Money Assessment** | • CompetitiveNeutrality = PublicSectorAdvantage - PublicSectorDisadvantage;  
• Nominal discount rate = (1 + real discount rate) x (1 + inflation rate) - 1; |
|-------------------------------|--------------------------------------------------------------------------------------------------|
| **Output Services**           | • OutputService -- has type -- (CoreService; EnablingService;)  
• MonitoredData -- has type -- UserFeedback;  
• (Regulator; publicAuthority; PrivateParty; ExternalMonitor) -- has role -- MonitoringUnit;  
• ServicePerformanceFailure -- results in -- PerformanceBond, GovernmentStepIn;  
• OutputService -- has -- ServiceImportanceLevel;  
• ServicePerformanceFailure -- has -- FailureSeverityLevel;  
• (FailureSeverityLevel, ServiceImportanceLevel) -- determines (PenaltyPayment; TerminationForPrivateParty’sDefault; PerformanceBond;)  
• ServiceRequirementAdjustment -- adjusts -- ServiceRequirement; |
| **Payment Mechanism**         | • ServicePriceAdjustment -- adjusts -- ServiceUnitPrice;  
• (OperationRisk; OperationCost; EconomicRisk; CommercialRisk) -- contributes in -- ServicePriceAdjustment |
| **Dispute Resolution Mechanism** | • ResolutionMethod -- has type -- (Mediation; MutualDiscussion;)  
• (ExpertPanel; Regulator) -- has role -- MediationPanel;  
• ResolutionMethod -- provides -- SolutionToDispute;  
• SolutionToDispute -- resolves -- Dispute;  
• MediationPanel -- chosen by -- (PublicAuthority;
Adding the new tuples to PMM v1.0 generates a validated metamodel called PMM v1.1. Graphical representations of the PMM v1.1 viewpoints are provided in Appendix 8.4. To facilitate a comparison between the two versions, the two versions of each viewpoint are illustrated as a pair.
5. Chapter 5: Developing the Procurement Modelling Language (PML) based on PMM and Quantitative benchmarking of PML against UML

“The limits of my language stand for the limits of my world. All I know is what I have words for.”

(Ludwig Wittgenstein)

5.1 PML Development

The metamodels provide a conceptual definition of a particular domain which then brings a common understanding of the domain to the stakeholders. Stakeholders can generally benefit from the metamodel in two different ways. Firstly, the metamodel can be populated with generic (M1) and/or real (M0) information about the domain; such solutions are used as expert systems or decision support systems which provide the right information to the right person at the right time. The second way of using a metamodel, as described in the Methodology chapter, is to use it as an abstract syntax of a modelling language that can then generate consistent, well-formed and standard models of the domain because the model pieces are generated by ‘one’ integrated metamodel which keeps them as parts of ‘one’ integrated model. Depending on the metamodel’s level of abstraction the modelling language can be generic or be specified to a particular domain. Those metamodels used as an abstract syntax of a modelling language must be implemented by a concrete syntax which enables the modellers to bring the metamodel into practice. That is, the concrete syntax maps the metamodel concepts to the notations and acts as an interface between the metamodel and its users (modellers), so the modellers use the notations for developing the models. The concrete syntax can be developed by different languages including programing languages (e.g. Java or C++), modelling languages (e.g. UML or SysML) or natural languages (e.g. English or French). As described earlier, the Procurement metamodel means to extend and be used concurrently with the UPDM, but since the UPDM metamodel is officially implemented as a UML/SysML profile, here the PMM is implemented as a UML/SysML profile to ensure a consistent application of PMM and UPDM. However, as will be discussed in the Conclusion, further studies will consider the implementation of PMM by other languages.
The previous chapter explained how the Procurement Metamodel (PMM) has been developed and validated, but in his chapter the PMM is linked to UPDM and then implemented as a UML/SysML profile to be used in parallel with UPDM for modelling the ‘complex systems’ and their ‘procurement projects’. The UML profiling mechanism was described in the literature review and the process of using it to implement the PML is explained in the methodology chapter. The process of creating the PML is listed below and each step is explained in detail in the following sections.

1. Linking the PMM to UPDM
2. Creating the corresponding stereotypes for each concept
3. Developing the relationships and other domain rules
4. Creating the customised diagrams
5. Developing the process guide for language users

5.1.1 Linking the PMM to UPDM

As mentioned earlier, PMM is developed to be used with UPDM so the former models the specific system aspects, including the high level operations, services, functions, and physical parts, and the earlier models the contracting project used to procure that system. Therefore, both metamodels should be linked to each other through a systematic method to ensure there is no inconsistency, conflict, or redundancy between their concepts or their rules. For this purpose, the method provided by Selic [142] is adapted for this phase of the study to explain how a domain model can be mapped to the UML metamodel; however, since this is a systematic approach we can use it to map the PMM to UPDM. The following guidelines should be used for mapping domain concepts to UPDM metamodel elements:

1. Select a base UPDM metaclass whose semantics are closest to the domain concept semantics.
2. Check all the constraints that apply to the selected base metaclass to verify there are no conflicting constraints.
3. Check to determine whether any of the attributes of the selected base metaclass need to be refined. Constraints of this type may be used to define domain-specific default values of attributes and to eliminate attributes that may not be relevant to the domain (by setting their lower multiplicity bounds to zero).
4. Check to determine whether the selected base metaclass has no conflicting associations to other metaclasses. These would be conceptual links inherited from
UPDM that contradict domain-specific semantics in some way. Many of these can be eliminated by setting their lower multiplicity bounds to zero, but if this is not possible, it may not be the appropriate metaclass despite its semantic proximity to the domain concept.

The following examples show how mapping is conducted. The “PPP Functions and roles” viewpoint contains the following concepts: PublicAuthority; PrivateParty; EngineeringOrganization; Operator; Financier; Consumer; Consultant; Operation; Maintenance; Design; Construction. The first 7 concepts are the types of organisations. There is a concept in UPDM called ‘OrganizationType’, therefore all 7 of these concepts from PMM become this type of concept so they inherit all the properties of the ‘OrganizationType’ concept. There is no constraint or association in this concept, but it conflicts with other PMM concepts. Furthermore, all the attributes of this concept remain because they can all be useful in the PMM. The next 4 concepts refer to types of projects that are conducted in a typical PPP contract, so they become the type of a concept in UPDM called ‘ProjectType’.

Table 5-1 shows the PMM concepts and the corresponding UPDM concepts to which they are mapped.

<table>
<thead>
<tr>
<th>PMM Concept</th>
<th>UPDM/SysML concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>PublicAuthority</td>
<td>Organization Type</td>
</tr>
<tr>
<td>PrivateParty</td>
<td>Organization Type</td>
</tr>
<tr>
<td>EngineeringOrganization</td>
<td>Organization Type</td>
</tr>
<tr>
<td>Operator</td>
<td>Organization Type</td>
</tr>
<tr>
<td>Financier</td>
<td>Organization Type</td>
</tr>
<tr>
<td>Operation</td>
<td>Project Type</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Project Type</td>
</tr>
<tr>
<td>Design</td>
<td>Project Type</td>
</tr>
<tr>
<td>Construction</td>
<td>Project Type</td>
</tr>
<tr>
<td>Consumer</td>
<td>Organization Type</td>
</tr>
<tr>
<td>Consultant</td>
<td>Organization Type</td>
</tr>
<tr>
<td>RegulatoryStandard</td>
<td>SysML:: Requirement</td>
</tr>
<tr>
<td>EnvironmentalStandard</td>
<td>SysML:: Requirement</td>
</tr>
<tr>
<td>EnablingSystem</td>
<td>Capability Configuration</td>
</tr>
<tr>
<td>DesignOption</td>
<td>UPDM Operational and System Viewpoints</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>ServiceRequirement</td>
<td>SysML:: Requirement</td>
</tr>
<tr>
<td>ServiceKPI</td>
<td>Measure Type</td>
</tr>
<tr>
<td>MonitoringUnit</td>
<td>Role type</td>
</tr>
<tr>
<td>Asset</td>
<td>Capability Configuration / physical resource</td>
</tr>
<tr>
<td>AssetKPI</td>
<td>Measure Type</td>
</tr>
<tr>
<td>ProjectTimeline</td>
<td>UPDM::GanttChart</td>
</tr>
<tr>
<td>ManagementTask</td>
<td>Operational activity</td>
</tr>
<tr>
<td>ManagementRole</td>
<td>Role type</td>
</tr>
<tr>
<td>Skill</td>
<td>Skill</td>
</tr>
<tr>
<td>Year</td>
<td>Timeperiod</td>
</tr>
<tr>
<td>TimePeriod</td>
<td>Timeperiod</td>
</tr>
<tr>
<td><strong>Dependencies</strong></td>
<td></td>
</tr>
<tr>
<td>Contract</td>
<td>Contract</td>
</tr>
<tr>
<td>consists of</td>
<td>SysML::containment / composition</td>
</tr>
<tr>
<td>aggregates</td>
<td>SysML::aggregationn</td>
</tr>
<tr>
<td>specifies</td>
<td>SysML::Refine / Trace</td>
</tr>
<tr>
<td>has role</td>
<td>Fills Post</td>
</tr>
<tr>
<td>required skill</td>
<td>SkillOfPersonType</td>
</tr>
<tr>
<td>Conducts</td>
<td>OrganizationalProjectRelationship</td>
</tr>
</tbody>
</table>

### 5.1.2 Creating the corresponding stereotypes for each concept

As explained in the literature review chapter (UML Profiling Mechanism), to create a concrete syntax, UML stereotypes must be created to represent the abstract syntax (metamodel) concepts. A UML tool called MagicDraw and provided by the NoMagic company is used in this study. Figure 5-1 shows the stereotypes that represents the concepts of “PPP Functions and Roles” viewpoint.
Some of the PMM concepts do not need a separate stereotype because they are a property of another concept; for instance, the ‘DegreeOfCommitment’ concept is a property of ‘Financier’ so no stereotype is created for this concept. Table 5-2 indicates the PMM concepts that are now the properties of other concepts.

Table 5-2: The concepts turned into the property of other concepts

<table>
<thead>
<tr>
<th>Concepts turned into property</th>
<th>Property type</th>
<th>Owner of Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>FinancierDegreeOfCommitment</td>
<td>real</td>
<td>Financier</td>
</tr>
<tr>
<td>RiskBaseCost</td>
<td>real</td>
<td>Risk</td>
</tr>
<tr>
<td>CostOfRisk</td>
<td>Real</td>
<td>Risk</td>
</tr>
<tr>
<td>ConsequenceImpact</td>
<td>real</td>
<td>RiskState</td>
</tr>
<tr>
<td>Probability</td>
<td>real</td>
<td>RiskState</td>
</tr>
<tr>
<td>RiskStateCost</td>
<td>Real</td>
<td>RiskState</td>
</tr>
<tr>
<td>ServiceUnit</td>
<td>real</td>
<td>OutputService</td>
</tr>
<tr>
<td>ServiceUnitPrice</td>
<td>real</td>
<td>OutputService</td>
</tr>
<tr>
<td>ServiceImportanceLevel</td>
<td>real</td>
<td>OutputService</td>
</tr>
<tr>
<td>FailureSeverityLevel</td>
<td>real</td>
<td>ServiceFailure</td>
</tr>
<tr>
<td>LeastPresentValueOfRevenue</td>
<td>real</td>
<td>Revenue</td>
</tr>
<tr>
<td>AssetValue</td>
<td>real</td>
<td>Asset</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>CriteriaWeight</th>
<th>real</th>
<th>EvaluationCriterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProposalRank</td>
<td>real</td>
<td>Proposal</td>
</tr>
<tr>
<td>YearlyAmount</td>
<td>real</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>Amount</td>
<td>real</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>TotalAmount</td>
<td>real</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>NetPresentAmount</td>
<td>real</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>Payer</td>
<td>Organization Type</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>Payee</td>
<td>Organization Type</td>
<td>MonetaryItem</td>
</tr>
<tr>
<td>InterestRate</td>
<td>Real</td>
<td>Debt</td>
</tr>
<tr>
<td>ReturnOnEquity</td>
<td>Real</td>
<td>Equity</td>
</tr>
</tbody>
</table>

5.1.3 Developing the relationships and other domain rules

Once the metamodel concepts are implemented as stereotypes, the domain rules and constraints should also be embedded into the concrete syntax so that domain rules will be enforced into the models generated through the language. The domain rules are mainly encoded in the metamodel by defining the relationships between the concepts. For example, consider the following tuples: “Finance -- has type -- (Debt, Equity)”; “Financier -- has type -- (Lender, Shareholder)”; “Lender -- provides -- Debt” and “Shareholder -- provides -- Equity”. These tuples express some constraints of the domain such as: the debt must be provided by the lender and equity must be provided by the shareholder, and regulators, consultants, and service consumers cannot invest in the project because they are not recognised as financiers. Some concepts are related to each other through mathematical relationships; for instance the WACC (Weighted Average Cost of Capital) is calculated via the following formula: \( WACC = \frac{(E/V) \times Re + (D/V) \times Rd}{1 - Tc} \); where the contributing parameters are the Equity, Debt, ReturnOnEquity, CostOfDebt and CorporateTax, so the next step in developing the concrete syntax is implementing the relationships.

5.1.3.1 Creating dependency stereotypes

Like the concepts implemented as Class stereotypes, each relationship should be implemented by creating its corresponding Dependency stereotype. Figure 5-2 shows some of the Dependency stereotypes as examples. These stereotypes will be shown as the dashed lines in the modelling language (as shown in Figure 5-4 and Figure 5-6) which enable the modeller to link the model elements (the ones that are allowed to be related) together.
Figure 5-2: Examples of Dependency Stereotypes

5.1.3.2 Creating the derived properties

In UML based languages, the relationship between the elements are kept as the derived properties of the elements; derived properties are those whose values are calculated based on the value of other properties, or based on the events that occur in the run time; therefore, the derived properties of an element can record the elements which are linked to that element in the run time. For example, to implement the “Lender -- provides -- Debt” tuple in the metamodel means creating two properties. The “Provided Debt” property is created for the “Lender” stereotype (class) and the “Providing Lender” property is created for the “Debt” class. The values of these properties will be determined when an object of the “Lender” class is linked to an object of the “Debt” class through the “provides” dependency, so when an object of a Lender class (e.g. NAB) is linked to an object of a Debt class (e.g. NAB Debt) the value of the “Providing Debt” property of the NAB object should be set as ‘NAB Debt’ and the value of the “Provided Debt” property of the ‘NAB Debt’ should be set as “NAB”. For every stereotype a corresponding customisation class is created into which the derived properties and other rules of that class are written. The “customization classes” store the rules that should be enforced to the stereotypes. In other words, the customisation classes store the domain rules to regulate the generated models and ensure the integrity, consistency, and well-formedness of the generated models. Some customisation classes are shown in Figure 5-3 as an example.

Once the derived properties are created, the expressions should be written to determine how the value of the derived property is set; in the above example the expressions written for the defined properties are as follows:

“Provided Debt” property:

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<callExpressionSpecification
```
"Providing Lender" property:

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<callExpressionSpecification
  <taggedValues>
    <entry key="name">
      <value>Provides</value>
    </entry>
  </taggedValues>
  <type xsi:type="stereotypeType" profile="PMM Profile" stereotype="Lender"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"/>
  <type xsi:type="stereotypeType" profile="PMM Profile" stereotype="Financier"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"/>
  <type xsi:type="stereotypeType" profile="PMM Profile" stereotype="Public Authority"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"/>
  <argument xsi:type="lookupExpressionSpecification" symbol="THIS"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"/>
  <expression xsi:type="dslRelationExpressionSpecification"
stereotype="_18_3_516017c_1475502347000_259733_79252" includeSubtypes="true"
direction="DIRECT" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"/>
</callExpressionSpecification>
```

The piece of model that can be created by the above codes is shown in Figure 5-4, and the complete scenarios of project financing and other project aspects are demonstrated in chapter 6.
As mentioned before, the relationship between some of the concepts is expressed as a formula, so in this case the value of the derived property will be set by a formula and the related concepts will be the input parameters to that formula. For example, the “CostOfRiskState” is a concept calculated in the Risk Assessment and Management viewpoint, and whose value is calculated by a formula with the following concepts as input: RiskBaseCost, Probability, ConsequenceImpact:
CostOfRiskState = RiskBaseCost * Probability * ConsequenceImpact;

To implement this formula (rule) into the language, a derived property called “RiskStateCost” is created for the “RiskState” concept, and then the expression will be written to set the value of this property. This expression can be written in different scripting and programming language, but in this study Java script is used to write the formulae. The above formula is written in the language shown in Figure 5-5.

![Figure 5-5: Writing the formula in the PML by Java script](image)

5.1.4 Creating customised diagrams

The class stereotypes and dependency stereotypes are the construction blocks which enable the models to be created, but to provide stereotypes to the modeller, diagram panes should be created for each viewpoint. A diagram pane provides stereotypes as buttons which the modeller can drag and drop into the modelling area to create the objects of those classes. The objects can then be linked to each other by the dependency stereotypes, and the values of their properties can be set. Figure 5-6 illustrates the financing structure diagram pane as an example where the Lender and Debt buttons are dragged to the pane to create the objects and then the objects are called “National Australia Bank” and “NAB Debt”. The “provides” dependency is used to link them together. Thus, 15 diagrams are created for 15 viewpoints where each diagram has the class and dependency stereotypes used in that viewpoint. As Figure 5-7 shows, a new set of diagrams is added to the tool called “PPP Procurement Perspective” which contains the PML diagrams, so the modeller can create the diagram by clicking on their name.
Figure 5-6: Financing Structure diagram pane
These class based diagrams allow the modeller to create the model elements and link them together, but there are occasion where a set of stored information in the model must be seen in a table format because it presents the information in a better structure, therefore a table is created and coded for most diagrams to extract information from the class diagrams and represent the main elements and their properties. Thus the corresponding table to each class diagram will be automatically populated by diagram information and will be changed by changes in the class diagram and vice versa. Figure 5-8 shows the financing structure table to exemplify how the tables present the information in the diagrams.
5.1.5 Developing the process guide for language users

Once the diagram panes have been created, modellers can use them to create the model pieces which are all parts of ‘one’ integrated model. As mentioned before, the viewpoints have overlaps and dependencies which keep the diagrams related to each other. For example, the Financial Assessment viewpoint has dependencies to the following viewpoints: Project Costs, Project Financing, Payment Mechanism and Risk Allocation. Figure 5-9 illustrates the common concepts between this viewpoint and other related viewpoints. The dependency between the viewpoints (Diagrams) requires the modeller to use them in the right order, for instance, before using the Financial Assessment diagram, the Operation and Maintenance Costs, Transferred Risks, Revenue, Debt, Cost of Debt, Equity and Return on Equity must be modelled by their corresponding diagrams.
Figure 5-9: The related viewpoints to the Financial Assessment Viewpoint

To ensure the modeller in using the diagrams in the right order, a process guide in the form of an activity diagram is developed whereby the steps start to order the least dependent diagrams in the beginning and the dependent diagrams after them. As explained before, these diagrams are used by the Government and Private party, which is why the activity diagram does not have the swim lanes needed to separate the activities of actors (Government and Private party). The next chapter (Chapter 6) uses the PML diagrams to model a variety of real contracts in order to demonstrate the applicability of PML.
Chapter 4 used a metamodelling process to develop the first version of PMM (1.0), and a set of validation guidelines to improve the metamodel’s completeness, with the result that PMM 1.1 was generated. The previous part of this chapter used PMM 1.1 as the abstract syntax and created PML on its base, so in this part, a quantitative analysis is used to compare the PMM 1.0 and PMM 1.1 to different versions of UML (UML 1.1 to UML 2.0) as the universally accepted modelling language provided by OMG (Object Management Group). A method for assessing the metamodel by Ma et. al [150] is used to analyse and assess its internal characteristics and calculate the five quality properties called Reusability, Understandability, Functionality, Extendibility and Well-structuredness. But to calculate these properties, some metrics of the metamodel must be counted which are related to the number of meta-classes, meta-relations between the meta-classes, meta-attributes, and the size and structure of the metamodel. A list and description of the metrics is given in Table 5-3. Once the metrics have been identified, the following process is used to calculate the quality properties.
1. Calculating the quality parameters (Modelling Concept Size, Hierarchy, Coupling, Intention, Inheritance, Abstract Meta-class Size)
2. Normalising the quality parameters to convert the absolute numbers into relative numbers
3. Calculating the quality properties (Reusability, Understandability, Functionality, Extendibility and Well-structuredness)
4. Normalising the quality properties

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOH</td>
<td>This metric value is the number of metaclass inheritance hierarchies in a metamodel</td>
</tr>
<tr>
<td>ADI</td>
<td>This metric value signifies the average depth number of metaclass inheritance hierarchies in a metamodel</td>
</tr>
<tr>
<td>ANA</td>
<td>This metric value signifies the average number of metaclass from which a metaclass directly inherits</td>
</tr>
<tr>
<td>ANDM</td>
<td>This metric value signifies the average number of metaclasses with which a metaclass directly associates</td>
</tr>
<tr>
<td>ANM</td>
<td>This metric value signifies the average number of metaattributes of a metaclass</td>
</tr>
<tr>
<td>ANMC</td>
<td>This metric value signifies the average number of metacombinations of a metaclass</td>
</tr>
<tr>
<td>ANR</td>
<td>This metric value signifies the average number of well-formed rules of a metaclass</td>
</tr>
<tr>
<td>NAM</td>
<td>This metric value is the number of abstract metaclasses in a metamodel</td>
</tr>
<tr>
<td>NCM</td>
<td>This metric value is the number of specific metaclasses in a metamodel</td>
</tr>
</tbody>
</table>

### 5.2.1 Quality Parameters

Design size is a measure of the number of classes used in a design; in order to describe modelling ability and the structural complexity of metamodels, this technique divides design size into a modelling concept size and an abstract metaclass size to signify the number of specific and abstract metaclasses in a metamodel, respectively. Abstraction is a sub-parameter of coupling because it is realised by specific metaclasses through inheritance, and composition is a sub-parameter of intension which gives the meaning of a metaclass by specifying all the required properties. Coupling characterises the degree to which a metaclass can collaborate with others; it is measured using the average number of metaclasses with which the metaclass directly associates and the average number of metaclasses from which the metaclass directly inherits. Intension characterises the connotation of a metaclass; it is measured using the average number of metaattributes, the average number of well-formed rules, and the average number of combined relations in a metaclass.
According to the above, the following quality parameters are calculated using the metrics shown in Table 5-3:

1. Modelling concept size = NCM
2. Hierarchy = NOH
3. Coupling = ANDM + ANA
4. Intension = ANM + ANR + ANMC
5. Inheritance = ADI
6. Abstract metaclass size = NAM

Table 5-4 indicates the number of associations and inheritance relationships in each viewpoint of PMM 1.0 and PMM1.1; the calculated amounts for the above quality parameters are shown in Table 5-5.

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>PMM 1.0</th>
<th></th>
<th>PMM 1.1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Association links</td>
<td>Inheritance links</td>
<td>Association links</td>
<td>Inheritance links</td>
</tr>
<tr>
<td>PPP Functions and Roles</td>
<td>14</td>
<td>3</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Financing Structure</td>
<td>7</td>
<td>4</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Project Costs</td>
<td>10</td>
<td>19</td>
<td>4</td>
<td>22</td>
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<tr>
<td>Project Risks</td>
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<td>22</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Risk Assessment and Management</td>
<td>20</td>
<td>3</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Feasibility Assessment</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Financial Assessment</td>
<td>14</td>
<td>0</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Value for Money Assessment</td>
<td>11</td>
<td>2</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Output Services</td>
<td>18</td>
<td>1</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>Payment Mechanism</td>
<td>11</td>
<td>7</td>
<td>14</td>
<td>7</td>
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<td>----</td>
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<td>----</td>
<td>---</td>
</tr>
<tr>
<td>Dispute Resolution Mechanism</td>
<td>6</td>
<td>4</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Contract Termination Management</td>
<td>15</td>
<td>3</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Request for Proposal and Proposal</td>
<td>30</td>
<td>0</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>Bid Evaluation</td>
<td>3</td>
<td>10</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Contract Management</td>
<td>4</td>
<td>10</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Monetary Items</td>
<td>-</td>
<td>-</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>170</td>
<td>93</td>
<td>212</td>
<td>133</td>
</tr>
</tbody>
</table>

Table 5-5: Quality parameters calculated by the metrics

<table>
<thead>
<tr>
<th>Quality Parameter</th>
<th>PMM 1.0</th>
<th>PMM 1.1</th>
<th>UML 1.1</th>
<th>UML 1.2</th>
<th>UML 1.3</th>
<th>UML 1.4</th>
<th>UML 1.5</th>
<th>UML 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling concept size</td>
<td>126</td>
<td>169</td>
<td>110</td>
<td>105</td>
<td>120</td>
<td>167</td>
<td>168</td>
<td>214</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Coupling</td>
<td>2.98</td>
<td>3.08</td>
<td>3.36</td>
<td>3.16</td>
<td>3.58</td>
<td>4.35</td>
<td>4.62</td>
<td>5.29</td>
</tr>
<tr>
<td>Intension</td>
<td>1.75</td>
<td>1.92</td>
<td>2.16</td>
<td>2.01</td>
<td>2.2</td>
<td>2.55</td>
<td>2.85</td>
<td>2.91</td>
</tr>
<tr>
<td>Inheritance</td>
<td>2.5</td>
<td>2.75</td>
<td>2.46</td>
<td>2.29</td>
<td>2.45</td>
<td>2.92</td>
<td>2.93</td>
<td>3.87</td>
</tr>
<tr>
<td>Abstract Metaclass Size</td>
<td>50</td>
<td>55</td>
<td>10</td>
<td>13</td>
<td>13</td>
<td>25</td>
<td>26</td>
<td>46</td>
</tr>
</tbody>
</table>

As mentioned above, the calculated parameters are absolute numbers which cannot be used for a fair comparison, so a normalisation formula should be used to normalise the parameters. It can be seen from Table 5-5 that the difference between two neighbouring versions is not particularly significant except those between UML 2.0 and UML 1.5, and thus it is not appropriate to use common \((x - \text{MinValue})/(\text{MaxValue} - \text{MinValue})\) as a rule to normalize the values in Table 5-5, because this needs to take most of the values from UML 2.0 as
MaxValue. Similarly, \( x/\text{average value}, (\text{MaxValue} - x)/\text{MaxValue}, \) and \( x/\text{MaxValue} \) all are affected by the values from UML 2 as MaxValue. Considering the regularity of the values in Table 5-5, we use \( x/\text{MinValue} \) as a rule to normalize them. The normalized results are shown in Table 5-6.

<table>
<thead>
<tr>
<th>Quality Parameter</th>
<th>PMM 1.0</th>
<th>PMM 1.1</th>
<th>UML 1.1</th>
<th>UML 1.2</th>
<th>UML 1.3</th>
<th>UML 1.4</th>
<th>UML 1.5</th>
<th>UML 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling concept size</td>
<td>1.2</td>
<td>1.61</td>
<td>1.05</td>
<td>1</td>
<td>1.14</td>
<td>1.59</td>
<td>1.6</td>
<td>2.04</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Coupling</td>
<td>1</td>
<td>1.03</td>
<td>1.13</td>
<td>1.06</td>
<td>1.2</td>
<td>1.46</td>
<td>1.55</td>
<td>1.78</td>
</tr>
<tr>
<td>Intension</td>
<td>1</td>
<td>1.1</td>
<td>1.23</td>
<td>1.15</td>
<td>1.26</td>
<td>1.46</td>
<td>1.63</td>
<td>1.66</td>
</tr>
<tr>
<td>Inheritance</td>
<td>1.09</td>
<td>1.2</td>
<td>1.07</td>
<td>1</td>
<td>1.07</td>
<td>1.28</td>
<td>1.28</td>
<td>1.69</td>
</tr>
<tr>
<td>Abstract Metaclass Size</td>
<td>5</td>
<td>5.5</td>
<td>1</td>
<td>1.3</td>
<td>1.3</td>
<td>2.5</td>
<td>2.6</td>
<td>4.6</td>
</tr>
</tbody>
</table>

By comparing PMM 1.0 and PMM 1.1, the ‘modelling concept size’ and ‘abstract metaclass size’ are increase because in the first validation method (Comparison against other guidelines) 48 new concepts (5 abstract and 43 specific) are added to ensure the completeness of PMM 1.1. The abstract metaclass size of PMM 1.1 is higher than all the UML versions because the PMM is domain specific and UML is a general purpose language. The experience gained from improving the UML versions shows that having one main hierarchy in the language provides the best structure to the metamodel, so like UML 2.0, the PMM versions are designed to have one main hierarchy, even though there are 12 sub-hierarchies with different depths and an average depth of 1.09 and 1.2 in PMM 1.0 and PMM 1.1, respectively. The trend of growing the coupling and intension in the UML versions justifies that the growth in those properties from PMM 1.0 to PMM 1.1 is normal.

### 5.2.2 Quality Properties

According to the quality parameters, the quality properties can be calculated to assess the metamodel’s main features, where “Reusability” signifies the ability of a metamodel to contribute its constructs to the definitions of other metamodels. It is related to intension, the number of specific classes and abstract metaclasses, and the coupling between metaclasses. “Understandability” signifies the degree to which users will understand the contents of a
metamodel. It is inversely proportional to the number of concrete classes and abstract metaclasses, the depth of inheritance hierarchies, the number of metaclass hierarchies, and the coupling between metaclasses, because the greater their values, the more difficult the metamodel is to understand. Understandability is directly proportional to the intension of a metaclass because metaclasses with good intensions should fully define the nature of the objects they abstract.

“Functionality” signifies the modelling ability of a metamodel such that the more modelling elements (specific metaclasses) there are in a metamodel the stronger is its modelling ability. Moreover, strong intensions of metaclasses and strong coupling between the metaclasses of a metamodel will increase its functionality. “Extendibility” signifies the degree of difficulty in adding new modelling elements to a metamodel. The more metaclasses a metamodel has, the higher its extension scores, and the stronger the coupling between metaclasses in a metamodel is, the harder it is to extend because the extension points often relate to many metaclasses via strong coupling relationships. A metamodel is “well-structured” if it has well-structured architecture consisting of well-structured metaclasses; this requires a strong intension of metaclasses and concise coupling between the metaclasses.

The method [150] adopted for analytical benchmarking has identified the following formula where the quality parameters are used to calculate the quality properties. These formulae are used to calculate the quality properties of the PMM versions and then compare them to the UML versions, as shown in Table 5-7. As explained before, to make a fair comparison of the calculated numbers their properties are normalised using the same formula \((x / \text{Min Value})\) shown in Table 5-8.

- **Reusability** = 
  \[-0.3 \times \text{coupling} + 0.8 \times \text{intension} + 0.3 \times (\text{modelling concept size} + \text{abstract metaclass size})\]

- **Understandability** = 
  \[-0.2 \times \text{coupling} + 0.7 \times \text{intension} - 0.1 \times \text{inheritance} - 0.1 \times (\text{modelling concept size} + \text{abstract metaclass size}) - 0.2 \times \text{hierarchy}\]

- **Functionality** = 
  \[0.4 \times \text{coupling} + 0.4 \times \text{intension} + 0.2 \times \text{modelling concept size}\]

- **Extendibility** = 
  \[-0.2 \times \text{coupling} + 0.3 \times (\text{modelling concept size} + \text{abstract metaclass size})\]
- **Well-structured** = $-0.2 \times$ coupling $+ 0.8 \times$ intension $- 0.1 \times$ hierarchy

Table 5-7: Quality properties calculated using the quality parameters

<table>
<thead>
<tr>
<th>Quality Properties</th>
<th>PMM 1.0</th>
<th>PMM 1.1</th>
<th>UML 1.1</th>
<th>UML 1.2</th>
<th>UML 1.3</th>
<th>UML 1.4</th>
<th>UML 1.5</th>
<th>UML 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reusability</td>
<td>2.36</td>
<td>2.7</td>
<td>1.26</td>
<td>1.29</td>
<td>1.38</td>
<td>1.96</td>
<td>2.1</td>
<td>2.79</td>
</tr>
<tr>
<td>Understandability</td>
<td>-0.43</td>
<td>-0.47</td>
<td>-0.08</td>
<td>-0.34</td>
<td>-0.11</td>
<td>-0.41</td>
<td>-0.32</td>
<td>-0.23</td>
</tr>
<tr>
<td>Functionality</td>
<td>1.04</td>
<td>1.17</td>
<td>1.15</td>
<td>1.08</td>
<td>1.21</td>
<td>1.49</td>
<td>1.59</td>
<td>1.78</td>
</tr>
<tr>
<td>Extendibility</td>
<td>1.66</td>
<td>1.93</td>
<td>0.39</td>
<td>0.48</td>
<td>0.49</td>
<td>0.94</td>
<td>0.95</td>
<td>1.64</td>
</tr>
<tr>
<td>Well-Structured</td>
<td>0.5</td>
<td>0.57</td>
<td>0.56</td>
<td>0.41</td>
<td>0.57</td>
<td>0.58</td>
<td>0.69</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 5-8: Normalized quality properties

<table>
<thead>
<tr>
<th>Quality Properties</th>
<th>PMM 1.0</th>
<th>PMM 1.1</th>
<th>UML 1.1</th>
<th>UML 1.2</th>
<th>UML 1.3</th>
<th>UML 1.4</th>
<th>UML 1.5</th>
<th>UML 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reusability</td>
<td>1.87</td>
<td>2.14</td>
<td>1</td>
<td>1.02</td>
<td>1.1</td>
<td>1.56</td>
<td>1.67</td>
<td>2.21</td>
</tr>
<tr>
<td>Understandability</td>
<td>-0.91</td>
<td>-1</td>
<td>-0.17</td>
<td>-0.72</td>
<td>-0.23</td>
<td>-0.87</td>
<td>-0.68</td>
<td>-0.49</td>
</tr>
<tr>
<td>Functionality</td>
<td>1</td>
<td>1.13</td>
<td>1.11</td>
<td>1.04</td>
<td>1.16</td>
<td>1.43</td>
<td>1.53</td>
<td>1.71</td>
</tr>
<tr>
<td>Extendibility</td>
<td>4.26</td>
<td>4.95</td>
<td>1</td>
<td>1.23</td>
<td>1.26</td>
<td>2.41</td>
<td>2.44</td>
<td>4.21</td>
</tr>
<tr>
<td>Well-Structured</td>
<td>1.22</td>
<td>1.39</td>
<td>1.37</td>
<td>1</td>
<td>1.39</td>
<td>1.41</td>
<td>1.68</td>
<td>2.12</td>
</tr>
</tbody>
</table>

The better the intension of a metaclass is, the higher is its reusability because a metaclass with a good intension should fully define the nature of the object that it abstracts. The more metaclasses there are means there are more reuse points, therefore an increase in the number of concepts and intentions in the PMM versions means that PMM 1.1 is more useable than PMM 1.0. However, PMM 1.1 has a high reusability, and stands between UML 1.5 and UML 2.0.

Having an Understandable metamodel (language) means having the depths and the number of inheritance hierarchies as small as possible, the relations between metaclasses be as concise as possible, and the intension of metaclasses be as high as possible, under the premise of maintaining the modelling ability of the metamodel. The PMM versions are the least understandable metamodels compared to the UML versions, which is not surprising because the PMM versions have the highest number of abstract meta-classes and their modelling concept size is higher than all the UML versions except UML 2.0. Moreover, while the Intension has a positive effect on understandability it is reported to be the lowest in the PMM versions compared to the UML versions.
Functionality is directly proportional to the number of specific metaclasses, the intension of
the metaclasses, and coupling between the metaclasses. Inheritance, abstract metaclasses, and
hierarchy are used to define or organise modelling concepts, they are not related to
functionality, which is embodied by using modelling concepts and relations between these
concepts. Considering the quality parameters of PMM versions, the functionality of PMM 1.1
can be estimated as low to average because it stands between UML 1.2 and UML 1.3. The
PMM versions have the lowest number in the Coupling parameter, which increases their
quality properties, but functionality is directly related to the coupling which makes the PMM
versions to be less functional than most of the UML versions. Having the lowest amount of
Intension is the other reason why PMM functionality decreases, and because Intension has a
positive effect on all the properties to which it is suggested.

The extendibility of a metamodel is directly proportional to the number of its specific and
abstract metaclasses, and is inversely proportional to coupling between its metaclasses.
Extendibility is only concerned with which extended metaclasses can be extension points and
couplings between metaclasses so that new modelling concepts can be added easily, so it is
not related to intension and hierarchy. This makes both PMM versions the most extendable
metamodels of all those which were compared.

Well-structured property is related to the coupling, intension and the hierarchy parameters,
but since Intension has a high impact on this property (+0.8) it makes the PMM versions
average well-structured, so PMM 1.1 is equal to UML 1.3, close to UML 1.4, and less than
UML 1.5 and UML 2.0. This again emphasises the importance of Intension in a metamodel
and the need to increase it in PMM 1.1.

A brief interpretation of the above analysis suggests that the developed metamodel is more
reusable than UML because of having more elements which makes it more effective in
modelling the infrastructure procurement. The large number of elements and many
dependencies between them has made the metamodel to be difficult to understand. This
suggests that even a modeller who is familiar with UML still needs training to work with the
procurement language. Although the number large number of elements has made the
language to be less understandable, it increases the extendibility which is a positive quality
point. As the intension of the metamodel is not high enough, its functionality and well-
structured features of the metamodel are less than UML which suggest the PMM has to be
improved in this aspect.
6. Chapter 6: Application and Demonstration of Procurement Modelling Language (PML)

“There is nothing less powerful than knowledge unattached, and incapable of application.”

(Samuel Butler)

6.1 Introduction

The previous chapters described the creation of Procurement Modelling Language (PML). Chapter 4 explained the development and validation of the Procurement metamodel (PMM). Chapter 5 implemented the PMM as a UML/SysML profile to develop the Procurement Modelling Language (PML) which can be practically used by modellers. In this chapter a variety of real projects from different sectors (Health, Transport and Road) and different countries (Australia, South Africa, India) will be modelled by PML to demonstrate its application in real world cases.

The main challenge in applying PML to the real projects is that real projects are not available because they are usually classified as confidential documents. However, some real contracts have been partially published so to test all the viewpoints (diagrams) of PML, more than one project will be used. Using more than one project to develop one single and integrated model is a paradox which is practically unacceptable; for example, the project costing part of the model shown below comes from a hospital project in South Africa while the payment mechanism is from a tunnel project in Sydney, Australia. But despite the mixed use of projects in one model, this demonstration can still be used to explain how the language works. Table 6-1 indicates the real projects used to demonstrate the language and Table 6-3 is a matrix which shows the cases used to demonstrate the viewpoints, and since the viewpoints are shown by their numbers in the matrix, their names and numbers are shown in Table 6-2.

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Country</th>
<th>Sector</th>
<th>Project name</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Australia</td>
<td>Transport</td>
<td>Cross City Tunnel contract, 2008 [184]</td>
</tr>
<tr>
<td>C2</td>
<td>Australia</td>
<td>Transport</td>
<td>RailCorp Rolling Stock Public Private</td>
</tr>
<tr>
<td>C3</td>
<td>Australia</td>
<td>Health</td>
<td>Partnership, 2012 [185]</td>
</tr>
<tr>
<td>----</td>
<td>-----------</td>
<td>--------</td>
<td>------------------------</td>
</tr>
<tr>
<td>C4</td>
<td>South Africa</td>
<td>Health</td>
<td>Gauteng Hospital, South Africa [173]</td>
</tr>
<tr>
<td>C5</td>
<td>India</td>
<td>Road, Waste Management</td>
<td>Vadodara Halol Toll Road Timarpur solid waste management project [187]</td>
</tr>
<tr>
<td>C6</td>
<td>Australia</td>
<td>Health</td>
<td>Hospital in Australia (Infrastructure Australia) [171]</td>
</tr>
</tbody>
</table>

Table 6-2: Viewpoints names and numbers

<table>
<thead>
<tr>
<th>VP no.</th>
<th>Viewpoint name</th>
<th>VP no.</th>
<th>Viewpoint name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PPP Functions and Roles</td>
<td>9</td>
<td>Output Services</td>
</tr>
<tr>
<td>2</td>
<td>Financing Structure</td>
<td>10</td>
<td>Payment Mechanism</td>
</tr>
<tr>
<td>3</td>
<td>Project Costs</td>
<td>11</td>
<td>Dispute Resolution Mechanism</td>
</tr>
<tr>
<td>4</td>
<td>Project Risks</td>
<td>12</td>
<td>Contract Termination Management</td>
</tr>
<tr>
<td>5</td>
<td>Risk Assessment and Management</td>
<td>13</td>
<td>Request for Proposal and Proposal</td>
</tr>
<tr>
<td>6</td>
<td>Feasibility Assessment</td>
<td>14</td>
<td>Bid Evaluation</td>
</tr>
<tr>
<td>7</td>
<td>Financial Assessment</td>
<td>15</td>
<td>Contract Management</td>
</tr>
<tr>
<td>8</td>
<td>Value for Money Assessment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6-3: Real cases vs Viewpoints matrix

<table>
<thead>
<tr>
<th>Case VP</th>
<th>vp 1</th>
<th>vp 2</th>
<th>vp 3</th>
<th>vp 4</th>
<th>vp 5</th>
<th>vp 6</th>
<th>vp 7</th>
<th>vp 8</th>
<th>vp 9</th>
<th>vp 10</th>
<th>vp 11</th>
<th>vp 12</th>
<th>vp 13</th>
<th>vp 14</th>
<th>vp 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.2 Application of PML to model real cases

As the previous chapter indicates, a process guide is developed to help modellers format the order of the activity diagrams, as shown in Figure 6-1. To demonstrate this modelling we will walk through the process guide and model the 15 viewpoints in the order shown below.

![Process guide for using the Procurement Modelling Language](image)

Figure 6-1: Process guide for using the Procurement Modelling Language

6.2.1 Output Services
System procurement commences by identifying a need, so a needs analysis is the first step in this process. The literature review showed that this step can be mapped on the Capability (Strategic) Viewpoints of UPDM, so those viewpoints will be used to define the strategic goals and the capabilities needed to achieve them. Since it is outside the scope of this demonstration, those UPDM viewpoints are not shown here. Once the required capabilities have been defined, the user requirements are written to explain the operations required by the system. In a conventional procurement method, user requirements are translated to system requirements and are prescribed to the contractors to be met. But, as mentioned in the introductory chapter, the requirements in Public Private Partnership contracts are written as the required output services, regardless of how those services are technically provided by the system. The system specifications will be provided as the UPDM System Viewpoints in the proposal issued by the bidders, as shown in Figure 6-1.

In the first step of this demonstration, the ‘output service’ viewpoint is used to record the output services and their refining service requirements. The “RailCorp rolling stock PPP” project is used to demonstrate this viewpoint, as shown in Figure 6-2.
6.2.2 Project Costs

Once the output services are written, the costs of the project must be estimated by the Government and to show how Costing is modelled; a hospital project in Ekurhuleni (South Africa) is used. The Gauteng Department of Health needs to provide a hospital and related services (to include medical equipment, catering and parking) in the Ekurhuleni area. The department has decided that the outputs will not include the provision of core medical services and direct patient care. The project term is assumed to be 12 years with a construction period of two years. Figure 6-3 shows the list of project costs estimated by the Gauteng Department of Health.
To model the project costs, predefined cost types are used, here the modeller should pick the right type of cost to create each element. For example, ‘Land acquisition and development’ is a type of ‘LandCost’ and ‘Payment to consultants’ is a type of ‘ContractDevelopmentAndManagementCost’. The cost elements have properties of ‘total amount’ and ‘per annum amount’ which store the cost values. Since the table has categorised costs into three categories, and to make the model easier to manage, three diagrams are created for the costs (Figure 6-4), and then the composite structure of each cost category is created, as shown in Figure 6-5: Direct Capital Costs, Figure 6-6: Direct Operation and Maintenance Costs and Figure 6-7: Indirect Operation and Maintenance Costs. To simplify reading the costs, a cost table (Figure 6-8) is created automatically based on the cost structure diagrams.
Figure 6-4: Three categories of costs in the hospital project case

Figure 6-5: Direct Capital Costs

Figure 6-6: Direct Operation and Maintenance Costs
6.2.3 Financing Structure

As the financing viewpoint shows, there are two main sources of finance to cover the project costs: debt provided by lenders and equity provided by shareholders. Both sources incur costs to the project because the debt plus interest must be paid back and equity will be collected by the shareholders plus a return on their investment (return on equity). The Financing sources
for the RailCorp Rolling Stock PPP Project, as shown in Figure 6-9, are used to demonstrate this viewpoint. Figure 6-10 shows how the Financing Structure diagram of the language models the project finances. A financing table is then automatically created based on the finance structure diagram (Figure 6-11); the numbers are not real, they are for demonstration only.

Figure 6-9: Sources of Finance in RailCorp rolling stock PPP Project

Figure 6-10: Finance Structure diagram models the finance sources and their providing financiers
6.2.4  Payment Mechanism

The Cross City Tunnel project is used to demonstrate this viewpoint. Every PPP project generates a cash flow which will cover the debts, debt interest equities and return on equities. This can be generated by payment of the users or by government, or a mixture of both. The Payment Mechanism viewpoint models the sources of payment and how they help to generate cash flow. The Cross City Tunnel (in Sydney, Australia) is used to demonstrate this viewpoint. The payment mechanism is written in the contract as follows:

- “For vehicles using the main tunnels to and from Darling Harbour, including vehicles entering from or exiting to the Eastern Distributor, $2.65 for all passenger vehicles and $5.30 for all heavy vehicles, including GST.”
- “For vehicles entering the westbound tunnel at Rushcutters Bay and then using the Riley Street tunnel to exit onto Sir John Young Crescent, $1.25 for passenger vehicles and $2.50 for heavy vehicles, all including GST.”
- “If the rate of GST changes in the future, the theoretical tolls will automatically increase or decrease to match this change.”

Figure 6-11: Finance table, automatically created by the tool
We assume that GST will increase by 4% in year 2014, and this will result in an increase in tolls by 4%. As Figure 6-14 shows, the increase in tolls leads raising the payments and therefore increases in the cash flow for year 2014. Note that an increase in the service price does not increase the revenue because the GST payable by the private sector (operator) has increased. In fact, the increase in the GST results in increase of the service price (tariff), however, the extra amount will be collected by the operator and paid to the government.
6.2.5 Project Risks

The next step in modelling the procurement project is to identify and evaluate the risks, and plan for their management. The hospital project in Ekurhuleni (South Africa) is used to demonstrate this viewpoint. Figure 6-15 shows that the valuation of Construction Risk as assumed by Department of Health, a client of this contract.

![Payment and cash flow table automatically created by tool](image)

Figure 6-14: Payment and cash flow table automatically created by tool

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Year</th>
<th>Per Annum Amount</th>
<th>Yearly Payments</th>
<th>Yearly Payment amount</th>
<th>Yearly Demand</th>
<th>Tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cash flow 2012</td>
<td>2012</td>
<td>2152500.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cash flow 2013</td>
<td>2013</td>
<td>2152500.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cash flow 2014</td>
<td>2014</td>
<td>2216000.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
As the figure shows, the Construction Risk has 4 subtypes:

- Cost overruns
- Time overruns, which may result in increased costs
- The cost of providing an alternative solution in case of delays
- The cost of upgrades should the facility not meet the needs of the Department of Health.

So, firstly the risks have to be created using the “Project Risks” diagram using the pre-defined risk subtypes, as shown in Figure 6-16.

The next diagram (Risk Management and Assessment) will be used to model the risk valuation.
6.2.6 Risk Assessment and Management

Once the risks are identified and their hierarchical structure created, they must be valued using the “Risk Assessment and Management” diagram. Here the ‘Construction Risk’ is chosen as an example of risk valuation. The assumptions made by the Department of Health and its transaction advisor on the cost and likelihood of the impacts can be valued as follows:

**Cost overruns**

Based on a similar project undertaken recently, the following probabilities show that the actual construction costs in relation to those assumed in the base PSC model:

- are the same as assumed in base PSC: 15 per cent likelihood
- exceed base PSC costs by 10 per cent: 40 per cent likelihood
- exceed base PSC costs by 15 per cent: 25 per cent likelihood
- exceed base PSC costs by 25 per cent: 15 per cent likelihood
- are less than base PSC by 5 per cent: 5 per cent likelihood.

**Time overruns**

The cost of delays is assumed to be R4 million per year. The institution and its transaction advisor have assumed the following to complete the hospital:

- completed on time: 15 per cent likelihood
- delayed by 1 year: 50 per cent likelihood
- delayed by 18 months: 25 per cent likelihood
- delayed by 2 years: 10 per cent likelihood.
Cost of providing similar services during the delay period, using the existing facilities:

The increased cost of using the existing facilities is assumed to be R3 million per year. The likelihood is directly linked to the likely time overruns and is therefore exactly the same.

In order to model the risk valuations by PML, the risk states of each risk are created and then the properties of each state (consequence Impact, Likelihood and Cost of risk state) are valued. For instance, the ‘Time overrun’ risk has four risk states called: ‘No Time Overrun, ‘Likely’, ‘Moderate’, and ‘Extreme’. The probability and consequence of those states are as the following pair respectively: (15%, 0), (50%, 0.04), (25%, 0.06), and (10%, 0.08). The cost of each risk state is calculated using the formula identified in the development of abstract syntax (see the metamodel viewpoints and formula in chapter 4).

\[
\text{Cost of Risk} = \text{Sum} (\text{Cost of Risk States});
\]

\[
\text{Cost of Risk State} = \text{Risk Base Cost} \times \text{Probability} \times \text{Consequence Impact};
\]

The costs of risk states are calculated as follows:

Cost of risk state (No Time Overrun) = 100 \times 0.15 \times 0 = 0

Cost of risk state (Likely) = 100 \times 0.5 \times 0.04 = 2

Cost of risk state (Moderate) = 100 \times 0.25 \times 0.06 = 1.5

Cost of risk state (Extreme) = 100 \times 0.1 \times 0.08 = 0.8

Cost of Risk (Construction Time Overrun) = (0 + 2 + 1.5 + 0.8) = 4.3;

The valuation of the 4 sub types of Construction Risk are shown in Figure 6-17.
Infrastructure projects typically have significant social and environmental impacts which arise from their construction and operation, which means that PPPs must have an environmentally and socially responsive development framework. While social and environment impact assessments are mandatory, there are few examples of how projects have proactively adopted best practices in this regard. The following are two different cases in India (Vadodara Halol Toll Road and Timarpur solid waste management project) which show how the PML can model the feasibility considerations of social and environmental risks in these specific cases. These cases are written in text format, but the text chunks are not stored in the PML elements, so the key feasibility elements are identified and recorded as instances of PML elements (stereotypes). The key terms of the cases are shown in italic format.

“The Vadodara Halol Toll Road was the first project that introduced environmental and social safeguards measures as part of the contractual obligation of the concessionaire. The environmental and social assessment for the project noted that in its original form it would lead to resettlement and rehabilitation of about 300 project affected families. Intense public consultations were carried out to develop various alternatives. Bypasses were introduced at various critical locations such that the extent of resettlement was reduced to only 10 project

6.2.7 Feasibility Assessment

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Risk Base Cost</th>
<th>Risk States</th>
<th>Probability</th>
<th>Consequence Impact</th>
<th>Cost of Risk State</th>
<th>Total Cost Of Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hospital Construction Cost overrun</td>
<td>100.0</td>
<td>Below Base PSC</td>
<td>0.05</td>
<td>-0.05</td>
<td>-0.3</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Change from PSC</td>
<td>0.15</td>
<td>0.0</td>
<td>0.0</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Likely</td>
<td>0.4</td>
<td>0.1</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.25</td>
<td>0.15</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extreme</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hospital Cost overrun</td>
<td>100.0</td>
<td>No Time Overrun</td>
<td>0.15</td>
<td>0.0</td>
<td>0.0</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Likely</td>
<td>0.5</td>
<td>0.04</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.25</td>
<td>0.06</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extreme</td>
<td>0.1</td>
<td>0.08</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Provision of similar service</td>
<td>100.0</td>
<td>Extreme</td>
<td>0.1</td>
<td>0.06</td>
<td>0.6</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Likely</td>
<td>0.5</td>
<td>0.03</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.25</td>
<td>0.045</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Delay</td>
<td>0.15</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hospital Upgrade Cost</td>
<td>100.0</td>
<td>Extreme</td>
<td>0.1</td>
<td>0.1</td>
<td>1.0</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Likely</td>
<td>0.4</td>
<td>0.05</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.3</td>
<td>0.07</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Upgrade</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-17: Risk valuation table
affected households.” In this scenario the ‘family resettlement and rehabilitation’ is a ‘Social risk’ and ‘Bypass’ is a ‘Risk management strategy’. These elements are created in the model using their respective stereotypes, as shown in Figure 6-18.

In another case, “the Timarpur solid waste management project, that was located in the vicinity of residential areas, organised public hearings to address concerns with respect to pollution.” In this scenario the ‘pollution’ and ‘organization of public hearing’ are the ‘Environmental Risk’ and ‘Risk management strategy’, respectively.

![Figure 6-18: The barriers that endanger the project feasibility](image)

### 6.2.8 Financial Assessment

The financial assessment viewpoint assesses two important financial factors of the project: Bankability and the Commercial Viability. Bankability refers to how attractive the project is to the banks (Lenders) to invest money into it, while the commercial Viability indicates the attractiveness of the project to potential bidders. The abstract syntax of this viewpoint suggests that project Bankability is related to the “Revenue” of the project and “Transferred Risks” to the private sector. Commercial viability is affected by three factors: The Project Internal Rate of Return (IRR), Weighted Average Cost of Capital (WACC) and Transferred Risks, where IRR and WACC are calculated by this viewpoint using the following formulae. The inputs to these formulae are determined by other viewpoints, for example, when
calculating the IRR, the amount invested (Debt and Equity) is determined in the Financing Structure viewpoint and the Operating cost is calculated in the Project Costs viewpoint.

Project Internal Rate of Return: \( \sum (R_i - I_i - C_i) / (1+r)^i = 0; \) \( r = ? \)

- \( R_i \) is the operating revenue at year \( i \)
- \( I_i \) is the amount invested at year \( i \)
- \( C_i \) is the operating cost at year \( i \)

**WACC** = \( (E/V)*Re + (D/V)*Rd (1-Tc) \);

- \( Re \) = cost of equity
- \( Rd \) = cost of debt
- \( E \) = market value of the firm’s equity
- \( D \) = market value of the firm’s debt
- \( V = E + D \)
- \( E/V \) = percentage of financing that is equity
- \( D/V \) = percentage of financing that is debt
- \( Tc \) = corporate tax rate

The models generated by this viewpoint will help the government to estimate the financial feasibility of the project based on their determining factors (which are shown by the “effects” relationship in the Figure 6-19). The financial assessment table reflects information from the structural diagram in a table format to facilitate the presentation of this information to the model readers, as shown in Figure 6-20.
6.2.9 Value for Money Assessment

The Public Sector Comparator (PSC) is the key management tool in a quantitative assessment of value for money during the procurement process, and the evaluation and comparison of bids. Bidders will be required to bid on an individual RFP (Request for Proposal) which includes an output specification and a contract, and which sets out the risks expected to be allocated to the bidders. The bids should first be assessed against the RFP to determine whether they are conforming bids, and then against the PSC. Bids should be evaluated to assess whether each proposal is based on the same level of risk transfer as set out in the RFP.
For instance, a bid may also accept additional risks that did not need to be accepted, but which may provide some additional value to government. The financial impact of the risks taken by government (i.e. Retained Risk) should be added to each bid to show the total project delivery cost.

The information used to demonstrate this viewpoint was gathered from a real case (hospital project) provided by the Australian Government (Infrastructure Australia) in [171]. Figure 6-21 sets out three conforming and three non-conforming bids for the project. The conforming bids are those which adhered to the requirements of the RFP, including complying with the risk allocation proposed by government and the output specification. (Output specifications were discussed in the output services viewpoint).

<table>
<thead>
<tr>
<th>Bids</th>
<th>Conforming bids</th>
<th>Non-conforming bids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSC</td>
<td>A</td>
</tr>
<tr>
<td>Raw costs (NPC – $m)</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>• service charge to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>government</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competitive Neutrality</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>• state taxes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risks valued by government</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Transferred Risks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design and construction</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>• operations</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>• maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPC-Subtotal</td>
<td>127</td>
<td>100</td>
</tr>
<tr>
<td>Retained Risks</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>• maintenance</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>• environmental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total NPC cost of services</td>
<td>152</td>
<td>125</td>
</tr>
</tbody>
</table>

Figure 6-21: Value for Money assessment of the bids against the Public Sector Comparator (PSC)

As the figure above shows, all of the conforming bids accepted the level of risk transfer outlined in the contract released with the RFP. In choosing from the complying bids, Bid A would be the most likely option because it has the same risk transfer structure as the other conforming bids, but has the lowest NPC cost of services to government. Moreover, Bid A’s NPC total cost of services is lower than the PSC’s total cost of services. Bidder A has
submitted a bid with an NPC of $100 million which includes Transferred Risk valued in the PSC at $40 million, but it excludes the Retained Risks valued at $25 million in the PSC. The total cost of the bid to government is the NPC of the bidder's service charges of $100 million and the costs of the Retained Risks, giving a total cost of $125 million. The risk adjusted Bid A of $125 million compares favourably against the PSC cost of $152 million.

Non-conforming bids should also be considered because the conforming bids may not necessarily present the best outcome for government. A review of three non-conforming bids D, E and F shows they accepted different combinations of risk transfer.

- Bid D: $98 million, includes transfer of design and construction risk and operational risk, but excludes maintenance risk (to be borne by government) valued at $5 million in the PSC.
- Bid E: $117 million, includes the transfer of design and construction, operational and maintenance risk and, in addition, accepts technology risk, valued at $15 million in the PSC.
- Bid F: $111 million, includes the transfer of design and construction, operational and maintenance risk and also accepts environmental risk, valued at $10 million in the PSC.

These examples show that all three non-conforming bids must be standardised so they can be compared. The bids are adjusted for the risks to be retained by government in order to calculate the revised cost of services to government, and to compare the bids against the PSC. With Bid E, this requires an environmental risk cost of $10 million (included in the PSC) to be added to the cost of the services, while Bid F requires the PSC’s technology risk of $15 million to be added to the cost of the bid. The non-conforming bids D, E and F are $128 million, $127 million and $126 million respectively.

Conforming Bid A still offers the best value for money in the absence of qualitative considerations, but non-conforming bids are still worthy of considering if they transfer a high variance risk which government may see value in transferring. This is a major issue to consider, particularly when comparing Bids E and F and the potential variability of technology risk compared to environmental risk.

To demonstrate the creation of value for money models, the PSC and two of the bids (A and D) have been modelled using the language. As explained in the abstract syntax of the Value for Money assessment (shown in Figure 6-22), the PSC and VFM consists of the following
concepts: Retained Risks, Transferred Risks, Raw PSC, Bid Price and Competitive Neutrality. To generate the models, these abstract concepts should be instantiated by the data/information of the real project.

PSC = Raw PSC + Transferred Risks + Retained Risks + Competitive Neutrality;
Competitive Neutrality = Public Sector Advantages − Public Sector Disadvantages;
NPC of Bidder = Bid Price + Retained Risks;
Raw PSC = Raw Costs − Third-party revenue
Transferred Risks = Risks transferred to the private party
Retained Risks = Risks retained by the public sector
Total Value of Retained and Transferred Risks = Sum (Total Value of aggregated Risks)

**Figure 6-22: Abstract Syntax of the Value for Money Assessment**

The PSC is modelled based on the abstract syntax and by using the data provided in Figure 6-21, as shown in Figure 6-24. The PSC consists of Raw PSC, the total cost of Retained Risks, and the total cost of Transferred Risks and Competitive Neutrality. The Raw PSC consists of Raw Costs which is a combination of Capital and Operating Costs. The Retained and Transferred Risks are the risks retained by the government and those transferred to the private sector, respectively. The Competitive Neutrality in this example is the state taxes which are a type of Public Sector Advantage (since they are payable by the private sector but not by the government). In order to model the risk allocation, the Risk Allocation Matrix is used, as shown in Figure 6-23. This matrix uses the “risk allocation” dependency to assign a risk to the group of Transferred Risks or Retained Risks. Figure 6-23 shows the risk allocation structures of the PCS, bidder A and Bidder D. As shown, the PSC and bidder A has
the same allocation structure while bidder D has a different structure (which makes it a non-conforming bid).

![Risk Allocation Matrix](image)  

**Figure 6-23: Risk Allocation Matrix**

The Total net present amount of PSC is calculated by the following formula:

\[
PSC = \text{Raw PSC (80)} + \text{Transferred Risks (40)} + \text{Retained Risks (25)} + \text{Competitive Neutrality (7)} = 152.
\]

The VFM models of bids A and D are created in the same way as shown in Figure 6-25 and Figure 6-26, respectively. The NPC of these bids are calculated by following formula:

\[
\text{NPC of Bidder} = \text{Bid Price} + \text{Retained Risks};
\]

\[
\text{NPC of Bidder (A)} = \text{Bid Price (100)} + \text{Retained Risks (25)} = 125;
\]

\[
\text{NPC of Bidder (D)} = \text{Bid Price (98)} + \text{Retained Risks (30)} = 128;
\]
Figure 6-24: PSC (Public Sector Comparator) model, created by the ‘Value for Money’ diagram pane

Figure 6-25: Value for Money model of Bidder A, created by the VFM diagram pane
Once the above models have been created, the value for money assessment table (Figure 6-27) is automatically generated by the tool to present useful data to the model readers and decision makers. The table shows that bidder A is the winner because it provides the best value for money compared to PSC and the other bidders.

### 6.2.10 Dispute Resolution Mechanism

The dispute resolution mechanism of the Cross City Tunnel project is used to demonstrate this viewpoint. The dispute resolution mechanism is described in the contract as follows:

Dispute resolution under the EA Agreement:

“For all disputes between EnergyAustralia and the Company other than those concerning the preparation and review of the Company’s design documentation and the preparation of ‘layout’ design documentation by EnergyAustralia,
- The dispute had to be notified, with details, in writing
- If the parties’ project managers could not resolve the dispute within ten days, either party could refer the matter to mediation, by a mediator selected using procedures set out in the EA Agreement, and
- If (but only if) the dispute was not resolved by mediation within six months, either party could commence court action.

For design documentation disputes,

- The dispute had to be notified, with details, in writing
- The parties then had to agree within five days on an expert to make a final, binding determination (if they could not, one was to be proposed by the Institution of Engineers, Australia)."

As the contract states, disputes are divided in two groups: design related disputes and all other disputes. With any of these types of disputes, a series of resolution methods are suggested, each of which has a priority and a period of time during which the method is valid. So based on the information provided and the abstract model of the Dispute Resolution Viewpoint, the resolution of design related disputes and all other disputes are modelled by the language, as shown in Figure 6-28 and Figure 6-29.

Figure 6-28: Dispute resolution model (For all disputes)
6.2.11 Contract Termination Plan

The Project Agreement can be terminated under a number of scenarios. The new Royal children’s Hospital Project in Victoria (Australia) is used to demonstrate this viewpoint. This contract was between the state of Victoria and a project company called CHP.

The Contract Termination plan is stated in the contract as follows: Where the Project Agreement is terminated before the natural expiry of the intended 25 year operating period CHP may be entitled to a termination payment. The basis for calculating the termination payment will be determined by the reason for the termination, as summarised below (Figure 6-30). Using the abstract model of the Contract Termination viewpoint, the information in Figure 6-30 can be modelled as shown in Figure 6-31. A contract termination table is also created by the tool to express the information in a more structured way, as shown in Figure 6-32.
6.2.12 Contract Management Plan

According to the guideline which shows the sequence of the diagrams, the last viewpoint of the contract is writing how the contract and other project activities are managed. As shown in the abstract model of the Contract Management viewpoint, the main concepts of this viewpoint are the management roles, including their tasks and the skills needed to perform
them, and since no real contract could be found with this information about contract management, this viewpoint is demonstrated by some assumptive information extracted from RailCorp Rolling Stock Public Private Partnership [185]. Figure 6-33 and Figure 6-34 shows the contract management plan in a structural and table format.

![Contract Management model](image1)

**Figure 6-33: Contract Management model**

![Contract Management table](image2)

**Figure 6-34: Contract Management table**

### 6.2.13 Request for Proposal and Proposal

As the guideline shows, once all the diagrams have been created they are put together to create a Request for Proposal and will be submitted for tendering. The created RFP is in a model format i.e. a set of interrelated elements such that any change in an element of the RFP will be automatically distributed to the rest of the elements and any changes needed to
maintain consistency of the RFP as a whole will be made, as shown in Figure 6-35. The bidders then receive the RFP and submit their proposal using the same language (PML) used by the public sector. Since these proposals are developed by one common and standard language, their evaluation and comparison can be done systematically, transparently, and more efficiently. A sample of a proposal is shown in Figure 6-36.

![Figure 6-35: The model of Request for Proposal](image-url)
6.2.14 Bid Evaluation

Once the bids are submitted they must be evaluated against a number of criteria. As identified by the abstract syntax, each criterion has a weight and a value which is calculated by the values of other elements or is assigned manually by the evaluation team. One of the important evaluation criteria for example, is the net present value of the value for money model, which in this case will be the same as the NPC of the value for money model of a bidder. The other example of a criterion is the output services where the evaluation team usually assigns value manually such that the lesser number is awarded to the better services. The following example shows how two bids are evaluated based on two criteria: Value for Money with a weight of 4 and output Services with a weight of 2; this evaluation is shown in Figure 6-37.
The proposal values are calculated as follows:

**Proposal Value = Sum (value of criterion * Weight of Criterion);**

**Proposal Value (A) = (VFM criterion value (125) * VFM weight (4)) + (Output services criterion value (30) * Output services weight (2))** = 560;

**Proposal Value (D) = (VFM criterion value (128) * VFM weight (4)) + (Output services criterion value (20) * Output services weight (2))** = 562;

A bid evaluation generates a lower number for proposal A than proposal D which makes proposal A the winner; the evaluation numbers are shown in Figure 6-38.
PPP Functions and Roles

After the winner and the financial close have been identified, the main organisations (financiers and engineering organisation) are identified, which means the PPP Functions and Roles viewpoint should be used to model the contractual relationships between those organizations. Figure 6-39 illustrates the contractual relationships of the RailCorp Rolling Stock PPP project; this figure can be modelled by the PML, as shown in Figure 6-40.
Figure 6-40: PPP functions and roles diagram
7. Chapter 7: Conclusion and Discussion

“Excellence is not a destination; it is a continuous journey that never ends”

(Brian Tracy)

7.1 Research Summary

The procurement phase of the infrastructure systems is as complicated and complex as the procured systems because while the systems engineering standards, methodologies and artefacts focus on the technical system to overcome its complexities, the complexities of the procurement project of these systems is overlooked and therefore not fully covered. This thesis analyses the existing systems engineering artefacts to determine how effectively they support procurement projects and identify their inadequacies, and then a variety of methods are used to develop the new artefact (Procurement Metamodel); this artefact extends the existing metamodels and improves their ability to cover the system build and procurement phase of the system.

The research begins by reviewing the suitability of the procurement methods for the infrastructure systems. The Public Private Partnership (PPP) is the most complete and flexible form of contract it can be structured like other types of contracts, and since it has recently become attractive to governments and private contractors due to its successful use in infrastructure procurement in Australia and overseas, PPP is used in this study to represent the procurement method of infrastructure systems. Following this, the main challenges and problems arising from the complexity of the procurement projects are identified. These problems stem from the complex procurement rules which are difficult to follow and apply; indeed, they are time consuming and costly processes of contract development and modifications that lack transparency in risk and cost calculations, risk allocations, financial assessments, and bid evaluation. The current procurement management methods are then reviewed to investigate their usability and effectiveness in managing such problems. The existing methods can be categorised in three groups: 1) text based documents such as government regulations, guidelines, and text based frameworks; 2) semi-modelled toolkits developed as excel sheets for financial calculations; 3) model based solutions with mainly model based frameworks (DoDAF and MoDAF) and their unified metamodel (UPDM). UPDM is officially recognised by the Object Management Group (OMG®) which makes it a reliable ground for an academic study. The UPDM metamodel is independent of any
language, but its official version is implemented as a UML and SysML profile. The inefficiencies of document based and semi-modelled solutions are discussed, followed by an explanation of the advantages of model based solutions which induces them to be adopted as best practice by leading systems engineering practitioners (NASA and DoD). UPDM is a metamodel developed to model complex procurement systems, which is why it will be analysed. The one to one mapping of UPDM viewpoints to the generic system lifecycle stages highlights its inability to completely address concerns about procurement and its activities. Therefore, this research hypothesise that a model based approach will lead to more successful PPP projects, where the success can be measured through a combination of on budget, on schedule and value for money. However, using these measures for assessing the effect of this language in success of real projects is very difficult and beyond this research, so this language will be assessed by comparing it against the existing procurement frameworks which are not used in metamodel development. So, the objective of this research is the development and validation of the procurement metamodel to extend UPDM to address the concerns of procurement stakeholders. The Literature review in chapter 2 describes this in more detail.

To achieve the defined objective, the metamodeling processes and methodologies are reviewed and then used to tailor a customised (but replicable) method to develop and validate the metamodel (Procurement Metamodel or PMM) and its implementation as a modelling language (Procurement Modelling Language or PML). This process is described in chapter 3.

The procurement guidelines published by the infrastructure and finance departments and the procurement agencies have been collected for sources of knowledge which are then separated into two sets of development and validation sets. A systematic method is consistently applied to the development set to extract the main concepts and combine them to create a PMM consisting of 15 viewpoints that will each address a set of stakeholder concerns. This development process is defined by how frequently these concepts occur so the importance of each concept is checked before being placed into the metamodel creation. To validate the PMM (version 1.0) a process is defined and then applied consistently; this process compares the metamodel to the guidelines of the validation set to identify any missing concepts and ensure the metamodel is complete. This validation leads to the creation of PMM 1.1. The development and validation of PMM versions are described in chapter 4.

The validated PMM (1.1) is the main artefact of this research, but it cannot be used by practitioners until it has been implemented in a tool; PMM is actually an abstract syntax of
the language which must be mapped to a concrete syntax as the user interface. As mentioned before, UPDM is implemented as a UML and SysML profile, so to have an integrated solution, PMM is implemented as a UML/SysML profile which allows the modellers to use UPDM and PMM concurrently in the same tool and develop consistent models of the technical system and its procurement project. The UML profiling mechanism is used to define the class and dependency stereotypes to represent the metamodel concepts and relationships. The domain rules are also written by scripting languages in the profile so they will be enforced on the models to ensure their well-formedness and compliance with the procurement regulations. The created stereotypes of each viewpoint are then grouped and provided with a diagram pane so they can be used to generate models in the same way as other UML diagrams. The metamodel viewpoints depend on each other through the common elements; which means the diagrams must be used in the right order because some elements will be created in one diagram before being used in another diagram. To help the modeller with the order of diagrams, a user guide is developed in the form of an activity model which shows the modelling process by suggesting independent diagrams in the beginning and dependent diagrams later on. The first half of chapter 5 explains the development of PML.

To assess the quality of PML, a quality assessment method is adopted which analyses the metamodel and identifies the six quality parameters called Modelling Concept Size, Hierarchy, Coupling, Intension, Inheritance and Abstract Metaclass Size. A series of formulae are then defined to calculate the quality properties of the metamodels, namely Reusability, Understandability, Functionality, Extendibility and Well-Structured. The second part of chapter 5 calculates the quality properties of the PMM versions (1.0 and 1.1) and compares them against the UML versions to benchmark PML against a universally accepted modelling language.

Once the PML has been developed it has to be applied in the real world to assess its applicability; a variety of real contracts from different countries and different sectors were collected to cover all the metamodel viewpoints and to enable all the language diagrams to be applied. Chapter 6 has demonstrated the use of language and synthetises the models of real contracts.

### 7.2 Research Contributions

According to the above descriptions, the contribution of this thesis can be summarised as follows. To clarify how the research contributions and achievements are aligned with the
goals of this research, each contribution is also compared against the defined objectives mentioned in section 1.4.

1. **Analysing and extending UPDM as the most recognised systems engineering metamodel:**

   A PMM is created to address the concerns of procurement stakeholders, but its requirements are also specified by considering the capabilities and inadequacies of UPDM. Therefore, before creating a PMM, a UPDM as the most widely used and academically approved metamodel is considered to make sure the created artefact only adds the missing concepts to UPDM and does not import any redundant materials into the body of knowledge; this approach ensures that the results of this thesis are unique and significant. This research contribution addresses the 1st objective of this study which is: To study how MBSE methods can be applied during procurement and whether they will meet the needs of the infrastructure procurement domain.

2. **A method composed of the best practices:**

   None of the existing methods could create the final artefact of this study (PML), so the best practices of the metamodeling processes and extension mechanisms were adopted to tailor a new customised method which can overcome the large size of the domain by breaking it into sub-parts, develop a piece of the metamodel for each part and then put them together to create a full metamodel, link the created metamodel to any other metamodel if needed, and implement the metamodel as a profile to develop a modelling language. This method is independent of any specific domain and can be replicated in the other studies to develop new modelling languages for other large and complex domains. Development of this method which was done based on reviewing and combining the other methods meets the 2\textsuperscript{nd} objective of this study which is: To study the different systematic approaches of metamodeling and language design to extend the current MBSE methods and improve their ability to support infrastructure procurement. Also, creating this method is towards achieving objectives 4 and 5 (4: To design, implement, and validate a procurement metamodel using the gathered knowledge; 5: To develop a modelling language based on the created metamodel.)

3. **Transforming the partially complete sources with a variety of structures to a standardised, well-structured and complete source:**
As shown in the guideline-viewpoint matrix, there is no guideline that covers every viewpoint of procurement, and since the procurement guidelines are published in different structures it is difficult to follow more than one of them in a project. Moreover, since many guidelines are developed by the use of each other, there is quite a lot of redundancy in the information about infrastructure procurement. Lastly, the guidelines are provided by different countries and different sectors which means they are not reliable outside their defined domains; albeit their information is of benefit to other countries or sectors. This study uses a systematic methodology to combine the sources of knowledge and transform them into a standardised metamodel which is complete, well-structured, irredundant, and applicable in all countries and sectors. This research contribution meets the objective 3 of this study (To review and gather the procurement guidelines and standards and create a complete source of knowledge and then create a complete and well-structured knowledge source.)

4. **Transforming the document based procurement regulations to the model based and machine executable rules:**

The procurement guidelines are published as text based documents so the rules and procedures must be read, understood and enforced by humans, and once a contract has been developed, compliance of the developed documents to the procurement rules must be checked manually. The solution provided by this thesis has been developed as a tool which contains the procurement rules in the form of executable codes that will automatically enforce the rules to the developed contract, which will be in the form of a model. Moreover, any changes in the regulations can be reflected into the metamodel, so reloading the profile onto the contract model identifies and notices any incompliance by the model with the new rules, so they can be modified automatically or manually to ensure the model based contract complies with the regulations. This research contribution directly addresses the defined goals of this study as defined in section 1.4. The 4th and 5th objectives of this study were development of a metamodel and a modelling language for procurement which allowed this research to make this contribution.

5. **Allowing the contracts to be developed as a consistent model instead of a text based format:**

As mentioned, since the rules are transformed into a metamodel, the contract will be developed as a consistent model instead of a pile of text materials. Each part of the procurement project is mainly dependent on the other parts, so any change in an element
will change the other project elements. Tracing the changes in document based materials while maintaining their consistency is laborious and prone to error, but in a model based contract, the changes are automatically distributed across the whole model so it can always be relied on as the source of truth because its consistency and integrity is maintained by an underlying metamodel. Figure 6-35 and Figure 6-36 illustrate the model based RFP and Proposal, respectively. These composite models consist of parts each of which constructed by interrelated and consistent elements. The examples of model based proposal RFP and proposal parts are shown in Figure 6-2 to Figure 6-34. This research contribution addresses the objective 6 of this study which is defined as: To apply and validate the language using real world case studies to assess its applicability and usefulness.

7.3 Discussion

The first step towards migrating from document based to model based solutions is the development of metamodels as a standard structure of text based documents. In this kind of modelling the model elements store pieces of text which are linked to each other even though their relationships are loose, i.e. changing part of a text in one element has no effect on the other related elements. A good example is the requirement diagrams of SysML language where every requirement is an element that stores a requirement in the text format. Although having a metamodel to structure the text is a step towards generating intelligent models, this is not yet a fully model based solution because in a true model based solution, the attributes or properties of model elements are tightly related to each other such that changing the attribute value of an element changes certain attribute values of the other related elements. This requires the model elements to store atomic data which cannot be broken down into any smaller parts. In this study, effort was put into developing a metamodel which is as close as possible to a fully model based solution. To achieve this goal, the granularity of the metamodel concepts should be fine so the model elements do not store pieces of text or composite data unless they are refined by some finer concepts. However, moving from large grain concepts towards fine grain ones increases the number of elements and therefore the size of the metamodel grows dramatically, therefore a balance is needed between the size of the metamodel and its granularity, i.e., between the breadth and depth of the metamodel. As mentioned, this study pushes the metamodel towards having fine grain concepts while keeping the metamodel broad enough to cover most of the important procurement viewpoints and address as many concerns as possible.
The other point worth discussing is categorising the metamodel concepts into viewpoints which are not separate modules; they categorise the metamodel concepts while having concepts in common. The current 15 viewpoints are created based on the structure of the guidelines, which allowed us to analyse the guidelines, extract the concepts, and structure the metamodel into a standard shape. The current format of the viewpoints can be called “phase based viewpoints” because they break the domain into phases, but the metamodel concepts can also be categorised into more different ways according to their common features. For example, by using the same concepts, a new viewpoint called “Operator Viewpoint” can be created by putting the operation related concepts (Operator, Operation and maintenance cost, operation risks, etc.) together; these viewpoints can be called “Stakeholder based viewpoints” and may include Government Viewpoint, Operator Viewpoint, Constructor Viewpoint, Financier Viewpoint, Consumer Viewpoint, Regulator Viewpoint and etc.

7.4 Limitations of the study

There were a number of constraints which limited this study and forced the research to select some particular paths to make progress. These limitations are as follows:

1. Accessing real contracts is very difficult.

   Documentation for procurement projects and contracts are usually classified as confidential which makes them difficult or impossible to access. As mentioned in chapter 4 (Knowledge gathering) this was one of the reasons why procurement guidelines were collected as knowledge sources rather than real contracts (domain instances). Since limited real cases are partially published, the PML application (chapter 6) uses six different real cases to cover all the metamodel viewpoints; this is not the most desirable situation although the application of PML on one real project provided a better demonstration.

2. Some evaluation metrics such as conciseness (concept importance) could not be assessed.

   The conciseness metric can only be assessed by frequent application of language to a variety of domains and calculating the usage frequency of each element. This approach identifies the more or less important concepts according to the frequency of their usage, but since there are not enough real cases available, this metric could not be assessed. However, as mentioned in chapter 4, the extracted concepts were nominated based on
how frequently they occurred in different guidelines, which makes the more important concepts enter into the metamodel. In the other words, the approach used to keep the metamodel concise moved from the validation stage to the development stage.

3. **The method used to develop the metamodel is a systematic process in which researcher knowledge cannot interfere.**

PMM is created by following a systematic method based on the concept of and frequency of extraction such that no concept is added or subtracted due to the researcher’s prior, although some concepts may appear to be excessive or missing, but they are not or added or subtracted to the metamodel. For example, ‘Wages and Salary’ is as type of Cost which is logically a sub-type of ‘Capital Cost’ and ‘Operation and Maintenance Cost’, but it is only shown as a sub-type of ‘Operation and Maintenance Cost’ because the occurrence of extracted concepts suggests this is the correct when in fact it is not. Although adding or subtracting those concepts can improve the quality of the metamodel, was not done because it requires a subjective interpretation by the solution developer, and therefore it must be done in consultation with experts. One of the future steps of this study is to design a systematic method for gathering and applying suggestions from experts to modify and improve the metamodel.

4. **Leaving out a number of viewpoints which are loosely related to the remaining viewpoints.**

A balance is needed between the breadth and depth of the domain in order to confine the size of the metamodel; so when analysing the structure of guidelines and selecting the main viewpoints the viewpoints are limited to those which are more dependent on each other and where their omission would make the domain definition incomplete. For example, the “Prequalification of Bidders” is a viewpoint which involves the government issuing a “Request for Qualifications” and the bidders submitting an “Expression of Interest.” Unlike the ‘Request for Proposal and Proposal’ viewpoint which uses the remaining metamodel concepts, the concepts used for this viewpoint (Prequalification of Bidders) are unlike other metamodel concepts and thus require their own set of concepts, and while this viewpoint adds value to the metamodel, its existence is conditioned by the size of the metamodel and therefore will be considered in the future studies.

5. **Limitations of the tool environment for implementing PML**
In this study a UML tool called Magic Draw developed by the NoMagic Company was used to implement PML, but its limitations affected the PML implementation. For example, the graphic user interface is not very user friendly which affects the attractiveness of the PML. Also, the javascript codes cannot be written directly into the metaclasses, so a complicated use of APIs is needed to implement the formulae. Therefore, some of the mathematical relationships which require the use of APIs are left for future improvements of this language.

7.5 Future studies

This study used a hybrid method of best practices to develop a metamodel and then a modelling language for PPP procurement. This language facilitates the development and modification of contracts and ensures their compliance with regulations. A number of further studies are suggested to extend this research to improve the final artefacts of this study and make them work more effectively.

1. Developing a concrete syntax based on natural languages such as English:

   Despite the advantages of developing the contracts as models rather than text based documents, government regulations have still not accepted the model based RFP and proposals. As mentioned before, since the abstract syntax (metamodel) is independent of any specific language, it can be mapped to other languages, so developing a concrete syntax in English and mapping the abstract syntax to it means that contract materials could be stored in an integrated model repository and contracts could be generated as text based documents. This means that any change in a contract can be traced by the underlying model and new documents are automatically generated from the model repository when needed. This approach makes this metamodel useable in countries whose policies do not allow for model based contracts.

2. Use of other contract types as knowledge sources

   This study focuses on the guidelines of PPP contracts as knowledge sources. As discussed before, PPPs are flexible and wide enough to cover the concepts of other contract types, but this metamodel is not yet approved for other types of contracts because it has not been proven systematically. To make this metamodel applicable to other types of contracts, future studies could collect the guidelines of conventional contracts and compare them to
the existing metamodel by defining a systematic process. The results of such a study could make this metamodel more generic and independent of contract type.

3. **Develop predictive models as relationships between the domain elements:**

The relationships between the domain concepts are identified by the metamodel, but by statistically analysing real cases, the predictive relationships between the financial and numeric concepts can be identified and thus make the metamodel more intelligent. For example, studies show there is a meaningful relationship between the Capital Costs and Operating Costs of a project, so a regression model of the previous projects could define a mathematical relationship between them. Decision makers will find these predictive models will help them make the right balance between the capital and operating costs at the project costing stage. Other examples of such predictive models are the relationships between the exchange rate risk and project IRR or between the operating supply materials risk and service unit price.

4. **Web-based implementation of the metamodel, instead of computer based tools**

The implementation of PMM in UML tools means that modellers and model readers must install these tools on the computer. Apart from the cost of the tools, being reliant on them actually decreases the portability of the solution, i.e., the language can only be used on a machine where UML tools have been installed. Implementing the language as a web-based tool allows users to store the model repository on a cloud, which makes the model to be accessible from any computer without resorting to any software installation. As mentioned before, the procurement model needs to be accessed by a variety of stakeholders, so the web-based implementation of this tool facilitates simultaneous access to the model by model owners at any privilege level.

5. **Overcoming the research limitations in future studies**

As mentioned in the previous part, there were some constraints which limited this research and a series of future studies can be carried out to address those constraints. The consistent following of a systematic process does not allow for any other interference into the process, so using the knowledge of experts in improving the metamodel quality is recognised as one of the future studies. Secondly, some important viewpoints such as “prequalification of bidders” can be added to the metamodel. The mathematical relationships between the concepts will be implemented in the language and the graphic
user interface can also be improved. As the mathematical formulae generate the numbers which are very critical to all the stakeholders, the tool should provide means for visibility and modifiability of the formulae. This allows modellers to realise how the numbers are calculated and modify the formula when needed e.g. in case of regulation changes.
8. Appendices

8.1 Appendix A: The full list of gathered guidelines

Table 8-1: List of all gathered PPP guidelines

<table>
<thead>
<tr>
<th>Source no.</th>
<th>Scope</th>
<th>Sector</th>
<th>Source name</th>
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<tbody>
<tr>
<td>2</td>
<td>Asian Developme nt Bank</td>
<td>Generic</td>
<td>Handbook for Integrating Risk Analysis in the Economic Analysis of Projects</td>
</tr>
<tr>
<td>4</td>
<td>Australia</td>
<td>Generic</td>
<td>National PPP Guidelines Volume 2: Practitioners’ Guide</td>
</tr>
<tr>
<td>5</td>
<td>Australia</td>
<td>Generic</td>
<td>National PPP Guidelines Volume 4: Public Sector Comparator Guidance</td>
</tr>
<tr>
<td>6</td>
<td>Australia</td>
<td>Generic</td>
<td>National PPP Guidelines - Overview - Infrastructure Australia</td>
</tr>
<tr>
<td>9</td>
<td>Canada</td>
<td>Generic</td>
<td>Preparing RFPs: A Ministry Guide to the Request for Proposals Process</td>
</tr>
<tr>
<td>10</td>
<td>CIPS</td>
<td>Generic</td>
<td>Contract Management Guide</td>
</tr>
<tr>
<td>11</td>
<td>EPEC</td>
<td>Generic</td>
<td>The European PPP Expertise Centre (EPEC), PPP Guide</td>
</tr>
<tr>
<td>12</td>
<td>ESCAP</td>
<td>Generic</td>
<td>A Guidebook on Public Private Partnerships in Infrastructure</td>
</tr>
<tr>
<td>13</td>
<td>European Commissio n</td>
<td>Generic</td>
<td>Guidelines for Successful Public-Private-Partnerships</td>
</tr>
<tr>
<td>14</td>
<td>Foster Infrastructur e Pty Ltd</td>
<td>Generic</td>
<td>Comparative Study of Variation Clauses in Public Private Partnership Contracts</td>
</tr>
<tr>
<td>15</td>
<td>Hong Kong</td>
<td>Generic</td>
<td>An Introductory Guide to Public Private Partnerships (PPPs)</td>
</tr>
<tr>
<td>16</td>
<td>Hong Kong</td>
<td>Generic</td>
<td>Practical Guide to Public Private Partnership (PPP) Projects</td>
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<td>Sector</td>
<td>Description</td>
</tr>
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<td>----------------------------------------------------------------------------</td>
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<tr>
<td>17</td>
<td>India</td>
<td>Water</td>
<td>Toolkit for public Private Partnerships in Urban water Supply</td>
</tr>
<tr>
<td>18</td>
<td>India</td>
<td>Generic</td>
<td>PPP in India toolkit</td>
</tr>
<tr>
<td>19</td>
<td>India</td>
<td>Transport</td>
<td>VFM-Indicator-tool</td>
</tr>
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<td>India</td>
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</tr>
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<td>Journal Paper</td>
<td>Generic</td>
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<td>25</td>
<td>OECD</td>
<td>Generic</td>
<td>Public Private Partnerships - In Pursuit of Risk Sharing and Value for Money</td>
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<td>PPIAF</td>
<td>Highway</td>
<td>Numerical simulation model for Highways - PPP projects</td>
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<td>The Toolkit for Public-Private Partnerships in Roads and Highways</td>
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<td>28</td>
<td>PPIAF</td>
<td>Highway</td>
<td>Graphical model for Financial Simulation of Highways - PPP Projects (PPIAF)</td>
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<td>QLD, Australia</td>
<td>Generic</td>
<td>Public private partnerships guidance material, Supporting document</td>
</tr>
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<td>30</td>
<td>QLD, Australia</td>
<td>Generic</td>
<td>Project assurance framework - Procurement options analysis</td>
</tr>
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<td>31</td>
<td>Scotland</td>
<td>School</td>
<td>Output Specifications - Building Our Future: Scotland's School Estate</td>
</tr>
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<td>South Africa</td>
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<td>National Treasury PPP Manual - Module 4: PPP Feasibility Study</td>
</tr>
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<td>34</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 5: PPP Procurement</td>
</tr>
<tr>
<td>35</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 6: Managing the PPP Agreements</td>
</tr>
<tr>
<td>36</td>
<td>South Africa</td>
<td>Generic</td>
<td>National Treasury PPP Manual - Module 1: South African Regulations for PPPs</td>
</tr>
</tbody>
</table>

38 UK Generic Standardisation of PF2 Contracts, HM Treasury (2012)


40 UK Generic Value for Money Assessment Guidance, HM Treasury - UK

41 US, UK, Australia, British Columbia, New Zeland Transport Key Performance Indicators in Public Private Partnerships

42 VIC, Australia Generic Partnerships Victoria, Practitioners’ Guide

43 VIC, Australia Generic Partnerships Victoria Guidance Material: Contract Management Guide

44 VIC, Australia Generic Partnerships Victoria - Public Sector Comparator Technical Note


46 World Bank Generic Concessions for infrastructure - A guide to their design and award

47 World Bank Generic Government Guarantees - Allocating and Valuing Risk in Privately Financed Infrastructure Projects

48 World Bank Transport Public Private Partnerships in Transport - WorldBank

49 World Bank Port Port reform toolkit, second edition

50 World Bank - PPIAF Generic How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets

51 World Bank - PPIAF Roads Matrix of Risks Distribution - Roads

52 World Bank, PPIAF Water Services Approaches to Private Participation in Water Services, A TOOLKIT

8.2 Appendix II: The phases and steps of guidelines

Table 8-2: Australia: Public Private Partnerships: Business Case Development, Financial Management Guidance No. 17, [146]

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Scoping Study| - Identify Service Need and Project Objectives  
|                 | - Establish Project Scope |
1. Mobilisation and Development of a Business Case

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Mobilisation and Development of a Business Case | - Conduct needs analysis, market testing and PPP feasibility study  
- Establish a PSCom and designate a Contract Manager  
- Establish whether a site is available  
- Establish what facilities/services are required  
- Prepare a draft Statement of Requirements  
- Consider whether to accept proposals for enhanced or other additional commercial facilities/services on the site  
- Assess risk  
- Prepare PSC and seek policy endorsement  
- Identify Key Stakeholders  
- Outline Delivery Options (Whole-of-life Costs, Risk Analysis, Constraints)  
- Submission to Government  
- Stakeholder Communication  
- Refine Project Scope  
- Document Project Plan  
- Undertake Risk Analysis  
- Develop PSC  
- Develop the Qualitative Assessment  
- Assessment of Market Interest  
- Assessment of Public Interest  
- Examination of Other Constraints  
- Recommendation and Submission to Government  
- Develop Expressions of Interest Documentation  
- Advertise Expressions of Interest  
- Evaluate Expressions of Interest  
- Request for Tender  
- Development of the Project Brief  
- Project Contract  
- Formal Bid Evaluation  
- Update Business Case  
- Value For Money Assessment  
- Determine Expected Budget Impact  
- Determine the Impact of Tax and Other Payments to Government  
- Submission to Government  
- Consideration of the communication issues  
- Contract Management  
- Monitoring Contract Performance  
- Contract Change Management  
- Closing project  

Table 8-3: Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs)
<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Inception    | - Register project with the relevant treasury  
|                 | - Appoint project officer  
|                 | - Appoint transaction advisor  
| 2. Funding      | - Submit a bid via the policy bureau for funds through the RAE process  
| 3. Technical Assessments, Consultation and Land Requirements | - Conduct appropriate technical assessments and socio-economic studies  
|                 | - Seek necessary authorities’ agreement on land use  
|                 | - Conduct consultations with stakeholders, Policy Committee and LegCo Panel  
| 4. EoI Exercise | - Initiate an EoI exercise  
| 5. Policy and Funding Approvals | - Consult and seek approvals of PWSC and FC  
|                 | - Determine detailed commercial arrangements  
|                 | - Seek draft land grant conditions  
| 6. Procurement and Selection | - Instruct DoJ on drafting of procurement documents/contract  
|                 | - Finalise procurement documents and seek approval from Central Tender Board  
|                 | - Establish bid evaluation committee  
|                 | - Issue RFP and conduct briefings/site inspections  
|                 | - Evaluate proposals  
|                 | - Negotiate with bidders and select from best and final offer(s)  
|                 | - Award contract  
| 7. Service Commencement | - Commence construction  
|                 | - Commissioning of facility  
|                 | - Commence service delivery  
|                 | - Establish and maintain close relationship with the consortium  
|                 | - Make payment for the facilities/services provided  
|                 | - Satisfactory performance?  
|                 | - Yes:  
|                 |   - Make payment for the facilities/services provided  
|                 |   - Conduct joint inspection towards the end of the contract  
|                 |   - Hand over facilities at the end of the contract  
|                 | - No:  
|                 |   - Defer or reduce payment  
|                 |   Continuous serious non-performance?  
|                 |     - Institute investigations and issue warning  
|                 |     Failure to perform?  
|                 |     - Initiate dispute resolution procedures  
|                 |     Problems not resolved?  
|                 |     - Step-in  
|                 |     - Terminate contract  

Table 8-4: South Africa: National Treasury PPP Manual
### Feasibility Study
- Needs analysis
- Options analysis
- Project due diligence
- Value assessment
- Economic valuation
- Procurement plan

Treasury Approval: I

### Procurement
- Design a fair, equitable, transparent, competitive, cost-effective procurement process
- Prepare bid documents, including draft PPP agreement

Treasury Approval: IIA
- Pre-qualify parties
- Issue request for proposals with draft PPP agreement
- Receive bids
- Compare bids with feasibility study and each other
- Select preferred bidder
- Prepare value-for-money report

Treasury Approval: IIB
- Negotiate with preferred bidder
- Finalise PPP agreement management plan

Treasury Approval: III

### Development
- Measure outputs
- Monitor and regulate performance
- Liaise effectively
- Settle disputes

### Delivery
- Report progress in the Annual Report

### Exit
- Scrutiny by the Auditor-General

---

### Table 8-5: Singapore: Public Private Partnerships Handbook, Version 2

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Invitation for Expressions of Interest | - Market Sounding  
- Invite Expressions of Interest |
| 2. Prequalification of bidders | - Setting up of the evaluation team  
- Prequalify the bidders |
| 3. Request for Proposal from selected bidders (Invitation to Tender) | - Refine the project appraisal  
- Tender Notice  
- Invitation to Tender (ITT) Documenting |
| 4. Market Period Feedback | - Seeking clarification by pre-qualified bidders  
- Submission of proposals |
Table 8.6: The European PPP Expertise Centre (EPEC), PPP Guide, [69]

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Project Identification        | - Project Selection and Definition  
                                  | - Assessment of PPP Option                                        |
| 2. Getting organised             | - Set up project team and governance structure  
                                  | - Engage team of advisers                                          
                                  | - Develop project plan and timetable                               |
| 3. Before launching the tender   | - Carry out further studies                                       
                                  | - Prepare detailed design of PPP arrangement                      
                                  | - Select procurement method                                        
                                  | - Select bid evaluation criteria                                   
                                  | - Prepare draft PPP contract                                       |
| 4. Bidding process               | - Procurement notice, prequalification and shortlisting           
                                  | - Invitation to tender                                              
                                  | - Interaction with bidders                                         
                                  | - Evaluation of tenders and PPP contract award                      |
| 5. PPP contract and financial close | - Finalise PPP contract                                         
                                  | - Conclude financing agreements                                    
                                  | - Reach financial close                                             |
| 6. Contract management           | - Attribute management responsibilities                          
                                  | - Monitor and manage project delivery and service outputs          
                                  | - Manage changes permitted in the PPP contract                     
                                  | - Manage changes not provided for in the PPP contract              
                                  | - Dispute resolution                                                
                                  | - When the contract ends                                           |
| 7. Ex post evaluation            | - Define institutional framework                                  
                                  | - Develop analytical framework                                     |

Table 8.7: India: PPP in India toolkit [35]

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. PPP Identification | - Strategic planning  
                                  | - Project pre-feasibility analysis                               
                                  | - PPP Suitability checks                                        
                                  | - Readiness Check 1                                             |
2. Full feasibility
- Reviewing plans for PPP project management
- Feasibility study and PPP due diligence
- Choosing the best-suited procurement method
- First draft of key project documents
- Readiness Check 2
- Application for In-principle Clearance

3. Procurement
- Preparing for procurement
- Market sounding – preparing and issuing an EOI
- Qualifying - Issuing RFQ and shortlisting bidders
- Preparing final drafts of key project documents
- Readiness Check 3
- Applying for Final Approval
- Bidding - RFP and bid evaluation
- Contract finalisation and award, and public disclosure of the PPP agreement

4. Contract management and monitoring
- Get the Concession Agreement right
- Establish the Contract management team
- Preparing a contract management manual
- Budget for and allocate the cost of contract management
- Involvement of the PPP Cell
- Monitoring performance
- Managing asset transfer at the end of the PPP
- Dispute resolution
- Deal with changes

<table>
<thead>
<tr>
<th>PPP stage/Phase</th>
<th>Activities/steps of the phase</th>
</tr>
</thead>
</table>
| 1. Identification, Prioritization and Selection of the PPP Project | - Identification of Potential PPP Projects  
- Prioritization  
- Decision Making and PPP Selection |
| 2. Due Diligence and Feasibility Studies | - Understand fully the characteristics of each project  
- Prepare the detailed Business Case for each project  
- Prepare the tender documentation  
- Procure the private partner  
- Negotiate from a position of strength following tender submission  
- Assist its inputs to operational project monitoring |
| 3. Procurement | - Define the Scope of Works  
- Define Expected Performance  
- Prequalification  
- Preparation of a draft contract  
- Bidding  
- Bid evaluation  
- Contract Negotiation and Award |
| 4. Contract Award | - Negotiations with the Private Sector  
- Financial Closure |
5. Contract Management

- Define outputs, performance levels and objective information requirements
- Performance monitoring
- Roles and responsibilities in monitoring
- Reporting of results arrangements.
- Mechanisms for benchmarking and testing where relevant
- Managing change mechanisms
- Mechanisms for problem solving and resolving disputes
- Contingency arrangements in case of failure or default
- Rights of the contracting agency

8.3 Appendix III: Concept extraction tables

8.3.1 PPP Functions and roles

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: PPP Functions and Organisation Roles</th>
</tr>
</thead>
</table>
European Commission: Guidelines for Successful Public-Private-Partnerships (pp 24, 83)

**PPP Functions:**
- Project Design, Procurement and Construction, Financing, Ownership, Operation and Maintenance, Marketing

  - Public Owner -- is -- (National Government, Local Government)
  - Private Concessionaire -- *(IFI debt, Commercial debt, Private Equity)* -- Public Owner
  - Private Concessionaire -- Contractor, Operator
  - Contractor -- Engineer

ESCAP: A Guidebook on Public Private Partnerships in Infrastructure (pp 11, 54)

**PPP Functions:**
- Engineering Procurement Construction (EPC), Operation and Maintenance, *Input Supply*, Other *Supply*

  - Government -- Concession/Contract Agreement -- Project Company (SPV)
  - Sponsors and Shareholders -- Equity -- Project Company (SPV)
  - *Customer/Government* -- Tariff -- Project Company (SPV)
  - Financiers -- Debt -- Project Company (SPV)
  - Project Company (SPV) -- Revenue -- Escrow Agent
  - Financiers -- Debt Service Payments -- Escrow Agent
  - *Experts* -- Project Company (SPV)

### Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Comparing Concepts: PPP Functions and Organizations Roles</th>
</tr>
</thead>
</table>
| **Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs)** (p 77) | *Government consultants* --- *consultancy contract* --- Government  
Government --- project agreement --- Consortium  
Consortium’s consultants --- consultancy contract --- consortium  
Shareholders --- shareholder agreement --- consortium  
Funders --- loan agreement --- Consortium  
Funders --- direct agreement --- Government  
Consortium --- construction contract --- Construction contractor  
Consortium --- operation contract --- Frontline service deliverer  
Consortium --- facilities management contract --- Facilities management contractor  
All contractors --- direct agreement --- Funders  |
Concessionaire -- *Reporting* -- Government  
Concessionaire -- Services -- *Consumers*  
Consumers -- Revenues -- Concessionaire  
Lenders -- Finance -- Concessionaire  
Shareholders -- Equity -- Concessionaire |
New Concepts:
Consumer; Consultant

New Tuples:
Consultant -- consultation contract -- (Engineering organization; PublicAuthority)
Consumer -- pays for services -- (PublicAuthority; Privateparty)

8.3.2 Financing Structure

Transferring responsibility to the private sector for mobilising finance for infrastructure investment is one of the major differences between PPPs and conventional procurement. While helpful for raising finance for large and highly leveraged investments, project finance comes at a cost because interest rates for project-finance debt are more expensive than government borrowing, and are often more expensive than borrowing by established companies. The aim of project shareholders and their advisors in developing the finance structure is typically to minimise the cost of finance for the project. Because equity is more expensive than debt, project shareholders use a high proportion of debt to finance the project.

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Financing structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank: Public-Private Partnerships Reference Guide, Version 2.0 (p.50)</td>
<td>Project finance has part: (Debt, Equity) Project Cost -- covered by -- Debt + Equity Lender -- provides -- debt debt -- has -- interest rate Shareholder (equity investor) provides -- equity equity -- has -- return rate</td>
</tr>
</tbody>
</table>
How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets
(p 53)

Private sector finance for PPP projects normally consists of a mixture of equity, provided by investors in the project, and third-party debt, provided by banks or through financial instruments such as bonds.

Projects can be financed using corporate finance—that is, lenders lend to the construction and operating and maintenance contractors, which in turn fund the project. Lender -- provides -- corporate finance -- to -- Engineering contractor

A Guidebook on Public Private Partnerships in Infrastructure, ESCAP
(pp 40-45)

Financiers -- Debt -- Project Company (SPV)

Debt -- has -- fixed maturity, fixed rate of interest

Sponsors and Shareholders -- Equity -- Project Company (SPV)

Government -- Provides -- Grant

Cost of capital = Return on debt x % of debt + Return on equity x % of equity

Numerical simulation model for Highways - PPP projects (PPIAF) (section 3.4)

Financial structure:

Investment Subsidy

Debt -- has -- interest rate -- grace period

Equity

**Validation Table:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Comparing concepts: Financing structure</th>
</tr>
</thead>
</table>
| Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects (p 101) | Subordinated Debt -- to -- SPV
Shareholder funds or Equity -- to -- SPV
Senior Debt -- to -- SPV |
| World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT (pp 90, 93) | Sources of Finance:

Equity -- provided by -- (project promoter, Other investors)
Loan -- provided by -- Local or Foreign Banks
Export credit guarantee finance
Loans --provided by -- development agencies
Grants -- provided by -- development agencies
Government -- provides -- (Equity, Loan)
Government -- provides -- Government Finance |
New Concepts:

WeightedAverageCostOfCapital (This concept is moved from the Financial Assessment Viewpoint and has replaced the CostOfFinance); CorporateFinance; CorporateGuarantee; FinancierDegreeOfCommitment (moved from Bid Evaluation viewpoint)

New Tuples:

(ReturnOnEquity, CostOfDebt, CorporateTax) -- contributes in -- WeightedAverageCostOfCapital;

Finance -- has type -- Corporate Finance;

Financier -- has -- FinancierDegreeOfCommitment;

PublicAuthority -- provides -- Debt

PublicAuthority -- provides -- CorporateGuarantee

Shareholder -- provides -- CorporateGuarantee

Debt -- has type -- CorporateFinance

Lender -- Provides -- CorporateFinance

### 8.3.3 Project costs

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Typical Costs</th>
</tr>
</thead>
</table>
| South Africa: National Treasury PPP Manual - Module 4: PPP Feasibility Study (p 50) | DIRECT COSTS:  
Capital costs  
Land costs  
Design and construction contract price  
Payments to consultants  
Plant and equipment  
Capital upgrade  
Life-cycle capital expenditure  
Maintenance costs  
Operating costs  
Wages and salaries  
Running costs |
<table>
<thead>
<tr>
<th>Management costs</th>
</tr>
</thead>
</table>

**INDIRECT COSTS:**
- Construction overhead costs
- Operating overhead costs
- Administrative overhead costs

**DIRECT COSTS:**

**Direct capital costs:**
- costs incurred in designing the project;
- raw materials;
- payments to external providers (i.e. contract price);
- costs of the public procurement process (including project development, documentation and contract management);
- payments to external consultants and advisers regarding project construction (financial, legal, engineering, patronage, other);
- plant and equipment (e.g. machinery and core IT platforms).

**Maintenance and lifecycle costs:**
- raw materials;
- tools and equipment;
- labour required for maintenance (wages and salaries).

**Direct operating costs**
- cost of inputs;
- employees directly involved in the service provision:
  - wages and salaries;
  - employee entitlements;
  - superannuation;
  - employee insurance;
  - training and development;
  - annual leave, long-service leave, expected redundancy payments;
  - travel;
- direct management costs;
- insurance.

**INDIRECT COSTS:**
Indirect Operating Costs:
- corporate overheads:
  - ancillary running costs (e.g. power, cleaning, stationery);
  - non-core IT and equipment (e.g. used for administration);
- administrative overheads:
  - employees not directly involved in the service provision;
  - facilities management;
  - overall project management;

Indirect Capital costs:
- partial commitment of plant and equipment;
- partial usage of new administration buildings.

| OECD: Public Private Partnerships - In Pursuit of Risk Sharing and Value for Money (p50) | 
| Direct costs: initial capital outlay and upgrades, and operating and maintenance costs; |
| Indirect costs: Administrative overhead costs, hidden/assumed costs, risk transfer costs, surplus capital costs, and third party revenues shares |

| Australia: Public Private Partnerships: Business Case Development, Financial Management Guidance No. 17 (p 48, 49) | 
| Direct Costs: |
| • direct capital costs – specific to service production, e.g. raw materials, plant and equipment, land and project construction costs, design costs; |
| • direct maintenance costs – clearly linked to servicing the project and/or infrastructure asset, rather than improving or adding to it, e.g. tools and equipment, labour costs; |
| • direct operating costs – relating to costs for everyday functions of the project, e.g. employee expenses, payroll tax, insurance, energy and waste management costs. |

| Indirect Costs |
| • construction overheads, e.g. site security; |
| • operating overheads, e.g. postage costs; |
| • corporate overheads, e.g. project teams; |
| • indirect capital, e.g. equipment and capital improvements; and |
| • whole-of-government adjustments, e.g. land tax, stamp duty and council rates. |

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>


### World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT (p 78)

**Operating and maintenance expenses:**
- Labour costs; electricity; chemicals; repairs to equipment;
- Depreciation (asset replacement);
- Return on capital (interest on debt; return on equity)

### Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs) (p 110)

**Direct costs:**
- Capital costs, e.g. costs for design and construction of a new facility; procurement of the required equipment and purchase/lease of land;
- Maintenance costs, e.g. costs of raw materials; tools/equipment; labour;
- Operating costs, e.g. costs of inputs and staff directly involved in the provision of services; insurance;

**Indirect costs:**
- Capital costs, e.g. costs for partial commitment of plants/equipment, partial usage of administration buildings;
- Operating costs: corporate overheads; administrative overheads (e.g. cost for employees not directly involved in the service provision, facilities management and project management, etc.)

### Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects (p 29)

**Capital Cost:**
- Design of the project
- • Land and development costs
- • Raw materials
- • Payments to external providers (i.e contract price)
- • Costs of the public procurement process (including project development, documentation and contract management)
- • Payments to external consultants and services regarding project construction (financial, legal, engineering, patronage and others)
- • Plant and equipment (e.g. machinery and IT platforms)
- • **Demolition**
- • **Inspection**
- • Modification/improvement/upgrades throughout the life of the project
- • **Permits**

**Indirect capital costs typically include:**
- • Partial commitment of plant and equipment
- • Partial usage of new administration buildings.

**Maintenance Costs:**
- raw materials; tools and equipment; labour required for maintenance

**Operating Costs:**
- • direct employment of the employees in the service provision, such as wages and salaries and benefits
- • Direct management costs
- • Insurance
- • Emergency and unplanned repairs
• Security  
• Repairs and maintenance  
• Support contracts, such as cleaning, landscaping, etc.  
• Tools and equipment  
• Materials and consumables.

NOTE: Comparing the above tables shows that this part of the Hong Kong guidelines have been copied from the Australian guidelines, which is why the extracted concepts are almost the same.

New Concepts:

RiskManagementCost (this concept is moved from the Risk Management and Assessment viewpoint)

DisputeResolutionCost; (this concept is moved from the Dispute Resolution viewpoint)

(Amount; TotalAmount; YearlyAmount; NetPresentAmount; are moved to Monetary Item viewpoint.)

New Tuples:

ManagementCost -- has type -- (RiskManagementCost; DisputeResolutionCost;)

RiskManagementCost -- has type -- InsuranceCost

8.3.4  Project Risks

The first step towards structuring a PPP is to put together a comprehensive list of all the risks associated with the project; such a list is known as a ‘risk register’. In this context a ‘risk’ is an unpredictable variation in the project’s value—from the point of view of some or all stakeholders—arising from a given underlying ‘risk factor’”. PPP risks vary depending on the country where the project is implemented, the nature of the project, and the assets and services involved. Nonetheless, certain risks are common to many types of PPP project.

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Typical Risks</th>
</tr>
</thead>
</table>
| (pp 147, 148)                                                          | Risk "has type":  
|                                                                        | Site: (Site availability; Site quality; environmental standard; geological condition)  
|                                                                        | Design and Construction: (Construction time overrun; construction cost overrun; Design and Construction quality)  
|                                                                        | Operation: (asset availability interruption; service availability interruption; network interface mismatch; O&M Cost overrun)  
<p>|                                                                        | Commercial risk (Demand, Fee collection), |</p>
<table>
<thead>
<tr>
<th>Source</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory or political, Change in legal framework</td>
<td></td>
</tr>
<tr>
<td>Default</td>
<td></td>
</tr>
<tr>
<td>Economic or financial (Interest rate; inflation; exchange rate)</td>
<td></td>
</tr>
<tr>
<td>Force Majeure</td>
<td></td>
</tr>
<tr>
<td>Asset ownership (Asset value risk; technology obsolescence risk)</td>
<td></td>
</tr>
<tr>
<td>Typical risks: Developmental risk; Sponsor risk Cost overrun risk Time overrun risk Input supply risk Operating risk Demand/revenue risk Change in tax rates Repatriation of capital and profit Force Majeure - Natural events Force Majeure - Political events Dispute between parties</td>
<td></td>
</tr>
<tr>
<td>Planning Risk Design and Construction Risk Operating Risk Demand Risk Residual Value Risk Other Financial Risk Legislative Risk</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Compared Concepts:</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------</td>
</tr>
</tbody>
</table>
| India: VFM-Indicator-tool (Page: Risk Values) | Construction Risks:  
Construction Cost Overrun Risk;  
Construction Time Overrun Risk;  
Operation Risks:  
Traffic Risk (Shortfall in traffic volume);  
Opex Risk; *Non-operation Revenue Risk*;  
PPP specific Risk:  
*Contract modification/renegotiation Risk*; |
| PPIAF: The Toolkit for Public-Private Partnerships in Roads and | Background risks:  
• Political, legal and regulatory risks;  
• Monetary/currency exchange rates and macro-economic risks |
| Highways (p 25-27) | • Force majeure  
Project Cost Risks:  
• *Project preparation risks*  
• Land acquisition risks  
• Environmental risks  
• Social acceptability of the project  
• Design risks  
• Construction, repair or rehabilitation risks  
• *Project management risks*  
• Technical operation risks  
Commercial Risks:  
Traffic level -- affected by -- alternative routes; tariffs; error in traffic studies;  |
|---|---|
| India: Public Private Partnerships in India: toolkit (Module 2, Phase 2, Risk Studies) | Pre-Operative Task Risks:  
Delays in land acquisition;  
*External linkages*;  
Financial Risk;  
*Planning*;  
Construction Phase Risks:  
Design Risk;  
Construction Risk;  
Approvals;  
Operations Phase Risks:  
Operations & Maintenance Risk;  
Volume Risk;  
Payment Risk;  
*Financial Risk*;  
*Non-Operations Revenue Risk*;  
Handover Risk Events:  
Handover Risk;  
Terminal Value Risk;  
Other Risks:  
Change in Law;  
Force Majeure;  
Concessionaire Risk;  
*Sponsor Risk*;  
*Concessionaire Event of Default*;  
*Government's Event of Default*;  |
| Hong Kong: Practical Guide to Public Private Partnership (PPP) | Land acquisition  
Level of demand for project |
Projects
(p 79)

Financial attraction of project to investors

High finance costs
Residual risks
Delay in project approvals to investors
Design deficiency
Unproven engineering techniques
Construction cost overrun
Construction time delay
Material/labour availability
Late design changes
Poor quality workmanship
Excessive control variation

Insolvency/default of sub-contractors or suppliers
Operation cost overrun
Operational revenues below expectation
Low operating productivity
Maintenance costs higher than expected
Maintenance more frequent than expected

New Concepts:

FinanceCostOverrunRisk; InflationRateRisk; ChangeOfLawRisk;

New Tuples:

Risk – has type – (DefaultOfPublicAuthority; DefaultOfPrivateParty; FinanceCostOverrunRisk; InflationRateRisk; ChangeOfLawRisk;)
RegulatoryAndPoliticalRisk – has type – ChangeOfLawRisk;
EconomicRisk – has type – InflationRateRisk;
FinanceCostOverrunRisk -- has type -- InterestRateRisk;

8.3.5 Risk Assessment and Management

To focus effort when allocating risks, it is often better to consider the importance of different risks because some will be much more significant than others: in terms of the likelihood of risk occurring, the severity of its impact on project outcomes, or both.
<table>
<thead>
<tr>
<th>Source</th>
<th>Risk Attributes</th>
<th>Risk Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Guide, Version 2.0</td>
<td>Risk State -- has part: Effect on PSC Base Cost (consequence Severity) (%)</td>
<td>Consequences</td>
</tr>
<tr>
<td></td>
<td>Impact of Risk ($)</td>
<td>Risk Value ($)</td>
</tr>
<tr>
<td></td>
<td>Likelihood (%)</td>
<td>Consequence Value = Consequence Impact * Base Cost * Probability;</td>
</tr>
<tr>
<td></td>
<td>Risk Value ($)</td>
<td>Risk Value = Sum (Consequence Values)</td>
</tr>
<tr>
<td>South Africa: National Treasury PPP</td>
<td></td>
<td>Risk – has -- Mitigation strategy</td>
</tr>
<tr>
<td>Manual - Module 4: PPP Feasibility Study</td>
<td></td>
<td>Mitigation strategy -- has -- Attendant cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk -- has -- Consequence, probability distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia: National PPP Guidelines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume 4: Public Sector Comparator Guidance</td>
<td></td>
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<tr>
<td>OECD: Public Private Partnerships - In</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pursuit of Risk Sharing and Value for</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
There are five major types of response:

1. **Risk avoidance**, whereby the source of risk is eliminated or is altogether bypassed by avoiding projects that are exposed to it.

2. **Risk prevention**, whereby actors work to reduce the probability of risk or mute its impact.

3. **Risk insurance**, whereby an actor buys an insurance plan – a common form of financial **risk transfer**.

4. **Risk transfer**, whereby actors relocate risks to parties who can best manage them.

5. **Risk retention**, whereby risk is retained because **risk management costs** are greater.

### Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways (p 28) | Impact of risk = Intensity of risk x Likely occurrence of risk  
Risks can be either (i) accepted, (ii) transferred, (iii) avoided or (iv) insured. |
| Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects (p 72) | Risk Treatment Options:  
risk transfer; risk reduction; risk acceptance; risk prevention;  
Risk treatment option -- involves -- Cost |

### New Concepts:

Insurance; RiskAcceptance; RiskAvoidance; RiskManagementCost (this is moved to costs viewpoint)

(Amount; YearlyAmount; NetPresentAmount; are moved to Monetary Item viewpoint.)

### New Tuples:

RiskManagementStrategy -- has type -- (RiskAvoidance; RiskAcceptance)
### 8.3.6 Feasibility assessment

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Feasibility Assessment</th>
</tr>
</thead>
</table>
Legal feasibility: Project -- has -- Legal barrier; entering to project -- has -- legal constraints  
Environmental and social sustainability: Project -- comply with -- Environmental Standard, Planning Standard) |
| World Bank - PPIAF: How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets (pp 55, 86-88) | Legal and Regulatory Assessment: entering into project agreement -- has-- Legal impediments; status of the dependent facilities or enabling systems  
Technical, Social, and Environmental Assessment: output requirements -- shown in -- design protocol; Design protocol -- relates to -- technology; technology -- has -- technical issue; output requirements -- requires -- operating and capital expenditure; Environmental and social risks; project -- comply with -- legal requirements and environmental policies |
| European Commission: Guidelines for Successful Public-Private-Partnerships (pp 81, 91) | Project appraisal: Local and national government policy; Extent of legislative Authority; Taxation framework; Reporting and accounting requirements; Financial issues; Technical and organisational issues; Political and social considerations; Ability to integrate different forms of funding |
| Australia: Public Private Partnerships: Business Case Development, Financial Management Guidance No. 17 (pp 21, 24) | Social and economic impacts: social benefits, design functionality, environment; Political impacts – regulatory issues, government policy, public debate; Organisational impacts – structure, change management, human resources, cultural changes; Operational impacts – service delivery, synergy, sustainability and technology |
| South Africa: National Treasury PPP Manual - Module 4: PPP Feasibility Study (pp 10, 11) | Service delivery arrangements: Services -- related to -- enabling services  
Technical analysis: assessment of the proposed technology  
Legislation and regulations: option -- comply with -- legislations and regulations  
Site issues: land use rights, zoning rights, geotechnical, environmental issues, relevant national or provincial heritage legislation, Environmental legislation  
Human resources |
**Validation Table:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>India: Public Private Partnerships in India: toolkit (Module 2, Phase 2, Full feasibility study)</td>
<td>Contents of a full feasibility study;</td>
</tr>
<tr>
<td></td>
<td>Market analysis and project scope;</td>
</tr>
<tr>
<td></td>
<td>Social and environmental feasibility;</td>
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<tr>
<td></td>
<td>Technical feasibility: *Environmental Condition -- impacts -- technical design;</td>
</tr>
<tr>
<td></td>
<td>*design option -- requires -- physical facilities;</td>
</tr>
<tr>
<td></td>
<td>*Risk studies;</td>
</tr>
<tr>
<td>PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways (Module 5, p 28)</td>
<td>Technical feasibility: A technical basis of the PPP project including <em>preliminary/basic design</em> and project cost.</td>
</tr>
<tr>
<td></td>
<td>Social impact studies: resettlement, indigenous people, gender and poverty analysis.</td>
</tr>
<tr>
<td></td>
<td><em>Risk assessment</em> including a preliminary allocation of risks.</td>
</tr>
</tbody>
</table>

**New Concepts:**

EnablingSystem; DesignOption;

RiskAssessmentAndManagementViewpoint; (this concept already exists in the metamodel, but was added to this viewpoint)

**New Tuples:**

OutputServices -- determine -- DesignOption;

OutputServices -- require -- EnablingSystems;

DesignOption -- determines -- Asset;

DesignOption -- constrained by -- RegulatoryStandard;

DesignOption -- constrained by -- Technology;

FeasibilityBarrier -- has type -- ProjectRisks;

**8.3.7 Financial assessment**

Whether a project’s overall revenue requirements are within the capacity of users, a public authority, or both, to pay for the infrastructure service involves checking the fiscal cost of the project (both in terms of regular payments, and fiscal risk) and establishing whether this can be accommodated within a prudent budget and other fiscal constraints.
<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Financial Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank: Public-Private Partnerships Reference Guide, Version 2.0 (p 53)</td>
<td>Commercial viability: whether the project is likely to attract good quality sponsors and lenders by providing robust and reasonable financial returns. Economic viability: economic benefits &gt; economic costs Bankability: Cash flow &gt; Debt Service + Margin; Lenders are concerned with -- Risks related to the Cash Flow AND Risk allocation Bankability definition: Operating cash flows must be high enough to cover debt service plus an acceptable margin. It also means that the risk of variation to the cash flows must be highly likely to stay within the margin. Lenders therefore carefully assess project risks, and how these risks have been allocated between the parties to the contract.</td>
</tr>
<tr>
<td>World Bank - PPIAF: How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets (pp 55, 86-88)</td>
<td>Financial Assessment: Project costs; project revenues; debt and equity funding required; exposure to inflation, long-term currency mismatch, or interest rate movements; Bankability: Lenders are concerned with -- risk allocation, Risk mitigation Bankability definition: Allocating a high level of risk to the private sector will reduce the amount that lenders are willing to lend to the project. The correct allocation and mitigation of risk are major factors in making projects bankable.</td>
</tr>
<tr>
<td>European Commission: Guidelines for Successful Public-Private-Partnerships (pp 81, 91)</td>
<td>Financial viability: Revenues -- be sufficient to service -- principal and interest payments on the project debt; provide a return on equity Assessing the private sector interest: Private sector is interested in: Sufficient demand; Revenue generating and development potential; Strong viability; Strong political commitment; Meet internal development criteria Socio-Economic Appraisal: Cost-benefit analysis; balance between social service provision and profitable services</td>
</tr>
<tr>
<td>South Africa: National Treasury PPP Manual - Module 4: PPP Feasibility Study (pp 10, 11)</td>
<td>Financial impacts: initial capital expenditure, capital and operational costs Funding and affordability: How is each option to be funded? Finance structure; Borrowing Capacity;</td>
</tr>
</tbody>
</table>

Validation Table:
Demand and traffic analysis;

Financial Analysis: It must show whether (or how) the project will be attractive to the private sector and whether any fiscal support is necessary and/or warranted. This will include an analysis of the funding options for the PPP project.

The WACC calculates a firm’s cost of capital in which each category of capital is proportionately weighted.

\[ WACC = \frac{E}{V} \times Re + \frac{D}{V} \times Rd (1-Tc); \]

Re = cost of equity
Rd = cost of debt
E = market value of the firm’s equity
D = market value of the firm’s debt
V = E + D
E/V = percentage of financing that is equity
D/V = percentage of financing that is debt
Tc = corporate tax rate

Financial Viability:

The project is considered to be financially viable when \( r \) is above a benchmark rate of return with respect to the country, sector and project characteristics. Generally it should be above 7% - 8% in real terms, depending upon countries and financial markets.

Project Internal Rate of Return (or Project IRR):

\[ \sum (Ri - Ii - Ci) / (1+r)^i = 0; \]

Ri is the operating revenue at year i
Ii is the amount invested at year i
Ci is the operating cost at year i

\[ WACC = (1-t) \left[ \frac{E}{K} \times Ce + \frac{D}{K} \times Cd \right] \]

t = amount of tax applicable
E = value of equity in the project
D = value of debt in the project
K = D + E
Ce = cost of equity/minimum return expected by equity investors
Cd = cost of debt/minimum return expected by debt investors

Commercial Viability:

\( \text{project internal rate of return (IRR)} \geq \text{weighted average cost of capital} \)
Asian Development Bank: Public-Private Partnership Handbook (p 17)

IRR:
\[\sum (R_i - I_i - C_i) / (1 + r)^i = 0;\]
- \(R_i\) is the operating revenue at year \(i\).
- \(I_i\) is the amount invested at year \(i\).
- \(C_i\) is the operating cost at year \(i\).

Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs) (p 58)

Bankability: The contract must be capable and likely to both repay the capital investment and provide an acceptable return over the life of the contract.

Revenue > Capital Investment + Return;

New Concepts:

WeightedAverageCostOfCapital; (This concept is also used in Finance Structure Viewpoint)

CorporateTax; ProjectInternalRateOfReturn;

New Tuples:

- (Equity, Debt, CostOfDebt, ReturnOnEquity, CorporateTax) -- contributes in -- WeightedAverageCostOfCapital;
- (Revenue, ProjectCosts, Debt, Equity) -- contributes in -- ProjectInternalRateOfReturn;
- (ProjectInternalRateOfReturn, WeightedAverageCostOfCapital) -- effects -- CommercialViability;

8.3.8 Value for Money Assessment

Concern: whether developing a project as a proposed PPP is the best way to achieve value for money compared to other options.

Source | Extracted Concepts: Value for Money Parts and steps
--- | ---
European Commission: Guidelines for Successful Public-Private-Partnerships (p 57-60) | 1. Costs:
- Net Cost Before Risk = Opportunity Costs + Capital Costs + Recurring Costs;
- NPV of Capital and Opportunity Cost;
- NPV of Recurring Costs;
- NPV of Total Costs (without risk);
- Equivalent Annual Cost;

2. Risk Analysis:
- Net Cost After Risk;
- NPV of Total Costs;
- Equivalent Annual Cost;
1. **Raw Cost**
   - **Direct Costs**: direct capital costs; direct maintenance costs; direct operating costs (fixed and variable costs)
   - **Indirect Costs**: construction overheads (e.g. site security); operating overheads (e.g. postage costs); corporate overheads (e.g. project teams); indirect capital, (e.g. equipment and capital improvements); whole-of-government adjustments, (e.g. land tax, stamp duty and council rates)
   - Determining the PSC Residual Value: the sale value of an asset
   - Calculating the Net Present Value (NPV)/Cost (NPC):
     \[
     \text{Present Value} = \sum \left( \frac{\text{Cash flow of year } t}{\text{Discount factor}} \right) \text{ for } n \text{ years}
     \]
     \[
     \text{Discount factor} = (1 + \text{Discount rate})^t;
     \]

2. **Competitive Neutrality**

3. **Transferable and Retained Risk**
   - Valuation of Risk
   - Identify the Transferable Risks
   - Identify the Retained Risks

<table>
<thead>
<tr>
<th>Australia: National PPP Guidelines Volume 4: Public Sector Comparator Guidance (pp 16-53)</th>
</tr>
</thead>
</table>

\[
\text{PSC} = \text{Raw PSC} + \text{Competitive Neutrality} + \text{Transferred Risk} + \text{Retained Risk}
\]

1. **Raw PSC** = (operating costs – third-party revenue) + capital costs
   - Third-party revenue = third-party service usage; excessive service capacity

2. **Competitive Neutrality** = land tax; local council rates; payroll tax; stamp duties (Public sector advantages).

3. **Transferred Risk** = Risks transferred to the private party
4. **Retained Risk** = Risks retained by the public party

Quantitative risk evaluation:
1) Identify all material risks
2) Quantify consequences of risk
3) Estimate probability of risk
4) Calculate value of all risks

<table>
<thead>
<tr>
<th>South Africa: National Treasury PPP Manual - Module 4: PPP Feasibility Study (pp 17-39)</th>
</tr>
</thead>
</table>

Part 1: Construct the base PSC model:

Step 1: Provide a technical definition of the project
Step 2: Calculate direct costs
Step 3: Calculate indirect costs
Step 4: Calculate any revenue
Step 5: Explain all assumptions (Discount rate; inflation rate) used in the construction of the model
Step 6: Construct the base PSC model and describe its results in Net Present Value (NPV)

The formula for calculating the NPV:

\[
\text{NPV} = CF_n \times \left[ \frac{1}{(1 + r)^n} \right]
\]
CF = cash flow for each period of the project

$r = \text{discount rate}$

$n = \text{number of periods over which the project is being considered}$

Part 2: Construct the risk-adjusted PSC model

Step 1: Identify the risks
Step 2: Identify the impacts of each risk
Step 3: Estimate the likelihood of the risks occurring
Step 4: Estimate the cost of each risk
Step 5: Identify strategies for mitigating the risks
Step 6: Allocate risk
Step 7: Construct the risk matrix
Step 8: Construct the risk-adjusted PSC model

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs) (p 110-115) | 1. Identify All Raw PSC Components: (Direct Costs; Indirect Costs; Third Party Revenue)  
2. Calculate Raw PSC: Raw PSC = (Capital Costs - Capital Receipts) + Maintenance Costs + (Operating Costs - Third-Party Revenue)  
3. Calculate Competitive Neutrality Adjustments: Competitive advantages from public sector ownership (amounts that should be added to a PSC) include exemption from rates, government rent, taxes, duties, fees and charges, accommodation costs, legislation/regulation, etc. which are only levied on or paid by private enterprises, while competitive disadvantages (amounts that should be deducted from a PSC) may also arise, e.g. heightened public scrutiny and reporting requirements which are not faced by private enterprises.  
4. Identify All Material Risks;  
5. Quantify Consequences of Risks;  
6. Estimate Probabilities of Risks;  
7. Calculate Value of Risks; Value of Risk = (Consequence x Probability of Occurrence) + Contingency  
8. Identify Desired Risk Allocation;  
9. Calculate Transferable Risk and Retained Risk;  
10. Calculate PSC; PSC = Raw PSC + Competitive Neutrality + Transferable Risk + Retained Risk |
Public sector procurement cost will be made up of:

- The costs of risks retained by the government
- The ‘Raw’ or basic costs and revenues of the project (All direct and indirect capital and operating costs and revenues)
- Adjustments for treating all public and private bids on the same basis e.g. *tax*
- The cost of transferable risks

Risks:
- Identification of risks involved in the project;
- Assessment of the impact of these risks;
- Assessment of the likelihood of such risks arising;
- The calculation of the financial impact and ranges of possible outcomes;

Costs:
- Capital costs;
- Operating costs;
- Projected revenues: Included only if bidders will be allowed to set tolls.
- Discounted cash flow: Selection of the Discount Rate is the most important issue and should represent the real opportunity cost of capital, adjusted for *inflation* (and subsidies, if any), for public projects.

**New Concepts:**

- CompetitiveNeutrality; PublicSectorAdvantage; PublicSectorDisadvantage;
- NominalDiscountRate; InflationRate (These Concepts are moved to Monetary Item viewpoint);

**New Tuples:**

- CompetitiveNeutrality = PublicSectorAdvantage - PublicSectorDisadvantage;
- Nominal discount rate = (1 + real discount rate) x (1 + inflation rate) - 1; (This equation is moved to Monetary Item viewpoint)

### 8.3.9 Output services
The output specification details the service requirements of government and seeks to improve the procurement and management of public infrastructure by focusing on the relevance, effectiveness and efficiency of a service provided, rather than its means of delivery.

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Tuples: Output services</th>
</tr>
</thead>
</table>
Contract -- specifies -- :  
1. Performance targets / output requirements  
2. Performance monitoring  
   - Who monitors (Contract Management team; Private Party; External monitors; Regulator; Users)  
   - What to monitor (Gathered Information)  
   - Report to whom  
   - Consequences for failure: ( Penalty payments; Liquidated damage; Performance bonds); Payment deduction (see payment mechanism); Termination for default (see Termination provisions)  
3. Step-in rights for the public party  
Output requirements should be SMART:  
Specified; Measurable; Achievable; Realistic; Timely  
Output requirements -- measured by -- Performance Indicators  
Output requirements -- has -- Time period  
Output requirements -- has type -- (core services, enabling services)  
Output requirements -- independent of:  
Technology; System Design; System Specifications |
| QLD, Australia: Public private partnerships guidance material, Supporting document (pp 27, 28) | Measurable output specification  
The output specification -- details -- service requirements  
Service specification -- independent of -- means of delivery  
Performance requirement -- must be -- measurable  
Performance requirement -- has -- relative importance  
Evaluation: Delivery Option -- compared to -- specified service requirements  
output specification may include:  
- site location  
- extent and quality of service required  
- latest date for commencement of service  
- performance measurement and reporting requirements  
- variation mechanisms  
- condition of project infrastructure at end of project life |
specified amount of services at defined levels

If the asset will be transferred back, then:
class/type of assets may also be specified

Required outputs -- deliver -- Required services

Types of output specifications:
- The main outputs -- deliver -- specified service;
- Ancillary outputs -- not directly related to -- main service
- Service -- has -- criticality level
- Input specifications;
- Conditions of assets at the time of handover

Quality of service output -- measured by -- KPI

Matrix : Service outputs x KPIs

Payment/Penalty regime -- linked to -- service availability & Service quality

Performance Management model -- consists of :
- Required performance level
- Means of Performance monitoring
  Independent Third party; Institution; end-user feedback; regulator;
- Consequences for failure
  Formal warnings; penalty deductions; performance bonds; eventual termination for private party default;

Performance monitoring:
- systematic self-monitoring
- review of the private party’s quality management system by the institution or an independent third party
- Monitoring : affordability of service; quality of service; performance

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| Hong Kong: Practical Guide to Public Private Partnership (PPP) Projects (pp 43, 85-92) | Output specifications -- lists --:
The extent and nature of services;
Service standards;
Details of Monitoring;
Support Services;
Service area -- has -- importance / criticality level;
Service -- has -- rectification period;
Service monitoring -- has type --:
- Systematic monitoring -- by -- contractor (Quality management system) |
- public authority -- reviews -- quality management system
- user feedbacks

Consequence of poor performance:

Failure -- has part -- **seriousness of Failure, accrued points**, financial impact of failure;

**Liquidated damage; Performance bonds; parent company guarantee; bonus payment for early service commencement;**

<table>
<thead>
<tr>
<th>Performance Specifications – Water Service PPPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Coverage Targets:</td>
</tr>
<tr>
<td>• Number of new direct household connections, or the percentage of households to be connected</td>
</tr>
<tr>
<td>• Percentage of roads with tertiary pipes</td>
</tr>
<tr>
<td>• Geographic area</td>
</tr>
<tr>
<td>- Quality Standards:</td>
</tr>
<tr>
<td>• Availability of service</td>
</tr>
<tr>
<td>• Pressure</td>
</tr>
<tr>
<td>• Water quality</td>
</tr>
<tr>
<td>• Effluent treatment</td>
</tr>
<tr>
<td>• Customer service</td>
</tr>
</tbody>
</table>

**Service Monitoring institutes:**

*Ministry; utility or asset-holding company; contract monitoring unit; independent regulator; Customers;*

**New Concepts:**

UserFeedback; PerformanceBond; ServiceImportanceLevel; FailureSeverityLevel; CoreService; EnablingService; ExternalMonitor;

ServiceRequirementAdjustment; Regulator; PrivateParty; PublichAuthority; GovernmentStepIn; (these concepts already exist in other viewpoints);

**New Tuples:**

- OutputService -- has type -- (CoreService; EnablingService;)
- MonitoredData -- has type -- UserFeedback;
8.3.10 Payment mechanism

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Payment mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank: Public-Private Partnerships Reference</td>
<td>Payment types:</td>
</tr>
<tr>
<td>(pp 160-162)</td>
<td>2. Government payments:</td>
</tr>
<tr>
<td></td>
<td>• Usage-based</td>
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<td></td>
<td>• Based on Availability</td>
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<td>• Upfront subsidies</td>
</tr>
<tr>
<td></td>
<td>3. Bonuses and penalties (fines)</td>
</tr>
<tr>
<td></td>
<td>Payment amount = Sum (Payment types)</td>
</tr>
<tr>
<td></td>
<td>- User Charges Payment</td>
</tr>
<tr>
<td></td>
<td>User charges payment amount = Tariff amount * Demand</td>
</tr>
<tr>
<td></td>
<td>Tariff Adjustment factors:</td>
</tr>
<tr>
<td></td>
<td>Economic Variables (Inflation)</td>
</tr>
<tr>
<td></td>
<td>Cost overruns</td>
</tr>
<tr>
<td></td>
<td>- Government Payments</td>
</tr>
<tr>
<td></td>
<td>Usage based: Demand risk -- allocated to private party / Shared Availability: Demand Risk -- allocated</td>
</tr>
<tr>
<td></td>
<td>to Government</td>
</tr>
<tr>
<td></td>
<td>Payments -- linked to Output specifications and Performance standards</td>
</tr>
<tr>
<td></td>
<td>Payment -- are indexed to Certain Risks (Operation risks and Inflation)</td>
</tr>
<tr>
<td></td>
<td>- Bonus and penalties -- related to Performance monitoring</td>
</tr>
<tr>
<td>ESCAP: A Guidebook on Public Private Partnerships in</td>
<td>Payment Mechanisms:</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>• Direct charging of users</td>
</tr>
<tr>
<td>(p 47)</td>
<td>• Indirect charging of (third party) beneficiaries</td>
</tr>
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<td></td>
<td>• Cross-subsidization between project components</td>
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<td></td>
<td>• Payment by the government (periodic fixed amount or according to use of the facility or service)</td>
</tr>
<tr>
<td></td>
<td>• Grants and subsidies</td>
</tr>
<tr>
<td>Australia: National PPP Guidelines Volume 2:</td>
<td>Payment mechanism elements:</td>
</tr>
<tr>
<td>Practitioners’ Guide</td>
<td>• availability of the service;</td>
</tr>
<tr>
<td></td>
<td>• performance of the service;</td>
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<tr>
<td>(p 56)</td>
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<td>--------------------------------------------------</td>
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<tr>
<td>• usage of the service;</td>
<td>+ 345</td>
</tr>
<tr>
<td>• quality of the private sector’s processes; and</td>
<td>+ 346</td>
</tr>
<tr>
<td>• wider defined benefits.</td>
<td>+ 347</td>
</tr>
<tr>
<td>Payment -- is based on -- Unitary charge for the service</td>
<td>+ 348</td>
</tr>
<tr>
<td>- Availability:</td>
<td>+ 349</td>
</tr>
<tr>
<td>Payment -- only to -- the extent that the service is available</td>
<td>+ 350</td>
</tr>
<tr>
<td>Availability -- measured by -- Performance Standards</td>
<td>+ 351</td>
</tr>
<tr>
<td>Performance measurement -- linked to -- set of standards or key performance indicators (KPIs)</td>
<td>+ 352</td>
</tr>
<tr>
<td>- Usage</td>
<td>+ 353</td>
</tr>
<tr>
<td>Payment -- determined by -- usage or volume</td>
<td>+ 354</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td>The payment may vary with:</td>
</tr>
<tr>
<td>• Availability of the service</td>
</tr>
<tr>
<td>• Performance quality of the service</td>
</tr>
<tr>
<td>• Usage of the service</td>
</tr>
<tr>
<td>- Availability:</td>
</tr>
<tr>
<td>Unitary Payment --is based on -- Unit of Service</td>
</tr>
<tr>
<td>Service -- measured by -- unit of measure</td>
</tr>
<tr>
<td>Service -- comply with -- performance standards</td>
</tr>
<tr>
<td>Availability -- has -- Start date , End date</td>
</tr>
<tr>
<td>Critical services -- higher effect on -- Penalties</td>
</tr>
<tr>
<td>Unavailability -- clearly defined</td>
</tr>
<tr>
<td>- Performance:</td>
</tr>
<tr>
<td>These should be defined:</td>
</tr>
<tr>
<td>Performance standard</td>
</tr>
<tr>
<td>Performance Monitoring</td>
</tr>
<tr>
<td>The consequences of a failure to meet the required standard</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>South Africa: National Treasury PPP Manual - Module 5: PPP Procurement (pp 73-76)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements of Payment mechanism:</td>
</tr>
<tr>
<td>1. Unitary payment for full availability and performance of the services</td>
</tr>
<tr>
<td>2. An appropriate indexation</td>
</tr>
<tr>
<td>3. A mechanism for penalising partial or complete failure of the availability and performance of the service by means of penalty deductions</td>
</tr>
<tr>
<td>4. No limit to deductions for non-availability</td>
</tr>
<tr>
<td>5. A mechanism for dealing with changes to service requirements</td>
</tr>
<tr>
<td>6. Provisions for any sharing of excess profits, if applicable</td>
</tr>
<tr>
<td>Service -- checks by -- availability , Performance Standards</td>
</tr>
<tr>
<td>availability , Performance Standards -- defined -- in the negative</td>
</tr>
<tr>
<td>Payment -- based on absence of -- Unavailability, performance failure</td>
</tr>
</tbody>
</table>
Price indexation -- only based on -- Inflationary increases

Partial or non-availability -- has -- penalty
Mal/non-performance -- has -- penalty

Payment change factors:
operating requirements

Key Performance Areas and KPIs
Economic Factors

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT (pp 108-110) | Price adjustments:

*Cost variation factors -- has type:*
- Inflation,
- sales tax,
- value-added tax,
- purchase price (price paid for buying the goods by operator as the retailer)

Cost variation factors -- increases -- tariff

*Opex overrun -- increases -- tariff*

Increased tariff -- paid by -- consumer

Tariff reset

Revenue = Demand * tariff

Demand -- co-relates to -- variable costs

Demand -- co-relates to -- Revenue

Tariff \( n = tariff \, n-1 \times \text{cost changes} \)

Cost changes -- correlated to -- Opex overrun Risk

Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs) (p54) | Payment -- based on -- service delivery:

Service delivery -- measured by -- criteria;

Payment types:

- Headcount/shadow toll/throughput

Based on the number of users of the facility

Revenues received from users
### New Concepts:

ServicePriceAdjustment;

(Amount; YearlyAmount; are moved to Monetary Item viewpoint.)

### New Tuples:

ServicePriceAdjustment -- adjusts -- ServiceUnitPrice;

(OperationRisk; OperationCost; EconomicRisk; CommercialRisk) -- contributes in -- ServicePriceAdjustment

#### 8.3.11 Dispute resolution mechanism

Defining a dispute resolution process helps to ensure disputes are resolved quickly and efficiently, without interrupting service—reducing the risk of disruption due to disputes to both public and private parties.

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Dispute Resolution Mechanism</th>
</tr>
</thead>
</table>
| World Bank: Public-Private Partnerships Reference Guide, Version 2.0 (pp 164-166) | Resolution mechanism:  
*Mediation*: Third party -- recommends *disagreement settlement*  
Recourse to a sector regulator: Regulator -- Resolves -- some dispute types  
Judicial system; Court -- solves -- dispute  
Panel of experts as arbitrators: Independent expert -- arbitrate -- dispute  
International arbitration: Permanent Arbitration Institution; International expert panel.  
Resolution Mechanism -- involves -- *Cost*  
Expert panel -- chosen by -- Private party, Government  
Expert panel -- propose -- *conciliatory terms*,  
*conciliatory terms* -- resolve -- disputes  
Expert panel -- arbitrates -- *arbitration decision*  
Regulator -- has type -- technical, economical |
| South Africa: National Treasury PPP Manual - Module 6: Managing the PPP Agreements (p 18) | Step 1:  
Dispute -- referred to-- institution *project officer, private party liaison officers*  
institution project officer, private party liaison officers -- offers -- solution  
Step2:  
Dispute -- referred to-- *accounting officer/authority of the institution, chief executive of the private party*  
Step 3: |
independent mediator or to an adjudicator
last priority:
Dispute -- send to -- courts
Costs of Court -- are usually shared

Project officer -- prevent -- dispute arising
project officer -- record -- problems
private party -- is notified of -- problems
project officer -- documents -- problem resolution approach

Partnership management plan -- used for -- dispute resolution

Dispute resolution methods:
Courts; Independent Regulator; Nonbinding ADR (Alternative Dispute Resolution); International arbitration

resolution method -- suitable for -- Concession type
Nonbinding ADR, International arbitration -- suitable for -- Many occasions for conflicts
Independent Regulator, Nonbinding ADR -- suitable for -- Long-term nature of relationship
Independent Regulator, Nonbinding ADR -- suitable for -- Public nature of services
International arbitration -- suitable for -- Large investment in immobile assets
Independent Regulator; Nonbinding ADR; International arbitration -- suitable for -- Complexity and sophistication of projects

Step 1:
Authority and Contractor consult with each other
Step 2:
Expert -- offers -- solution
Financial expert -- decide about -- price variations
Step 3:
Dispute -- refers to -- arbitration
Arbitration -- is a type of -- ADR (Alternative Dispute Resolution)
Arbitration -- Domestic and International Arbitrator;
Dispute -- refers to -- Courts

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>India: Public Private Partnerships in India: toolkit (Module 2, p 4, Dispute Resolution)</td>
<td>decisions are taken by an entity with the necessary technical, economic and financial expertise; Identify and resolve issues; Stages of dispute resolution:</td>
</tr>
</tbody>
</table>
- *Amicable resolution (mutual discussions)*,
- *Mediation*
- *Arbitration*

Mutual Discussion -- offers -- *solution*;

*Mediation*:
impartial third party: the conciliator/mediator;

*Arbitration*: *domestic arbitration*; international arbitration;
*Costs* are incurred on the process of arbitration;

---

**World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT**
(p 132)

**Record problems**

Institutions that can plausibly be used to resolve disputes include:

- *Negotiation* between the operator and the contracting authority
- Negotiation with the help of a *mediator*
- Negotiation informed by an independent expert
- Decision by an independent expert or experts
- Decision by *domestic or international arbitration*
- Decision by the courts.

---

**New Concepts:**

DisputeResolutionCost; Arbitration; DomesticArbitration; MutualDiscussion; Mediation; SolutionToDispute; ContractualIssue;

**New Tuples:**

ResolutionMethod -- has type -- (Mediation; MutualDiscussion;)
(ExpertPanel; Regulator) -- has role -- MediationPanel;

ResolutionMethod -- provides -- SolutionToDispute;

SolutionToDispute -- resolves -- Dispute;

MediationPanel -- chosen by -- (PublicAuthority; PrivateParty);

DisputeResolution -- records -- ContractualIssue;

Arbitration -- has type -- (InternationalArbitration; DomesticArbitration;)

---

**8.3.12 Termination Management**
<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Termination Management</th>
</tr>
</thead>
</table>
Contract length -- set by -- government  
Tariff or payment level -- propose by -- Bidder  

- Second option:  
tariff or annual payment -- set by -- government  
Contract length -- offered by -- Bidders  

- Third option:  
least present value of revenue (LPVR) - offered by -- Bidders  

- Early Termination:  
Contract Terminator; Termination reason; Compensation payment  
Reason types:  
- default by the private party,  
- termination by the public party, (for reasons of public interest)  
- external reason (force majeure). |
| World Bank: Concessions for infrastructure - A guide to their design and award (p 80-85) | Scheduled termination:  
concession's duration -- determined by -- bidding  

Early termination reasons:  
- Both parties agree.  
- The concessionaire has failed to meet its obligations (Default)  
- The concessionaire becomes bankrupt.  
- The service provided under the concession becomes inherently unprofitable,  

Handling simple cases:  
Contract length --determined by -- sunk investment length  

Handling Difficult Cases:  
Trade-off between the contract length with contract price  
concession's length to be determined endogenously -- by -- LPVR |
| UK: Standardisation of PF2 Contracts, HM Treasury (2012) (p 190)          | Termination -- has -- Compensation on Termination  
EARLY TERMINATION:  
Termination on Authority Default  
Termination on Contractor Default  
Termination on Force Majeure |
Termination on *Corrupt Gifts and Fraud*
*Voluntary Termination* by Authority

**Validation Table:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways (Module 5, p 130)</td>
<td>The contract -- must specify -- the required physical state of the project at contract end. Transfer back to Government must remain an option and to be decided by Government at the time. Plan a general audit several months before the end of the contract.</td>
</tr>
</tbody>
</table>
| EPEC: The European PPP Expertise Centre (EPEC), PPP Guide (p 39, 40) | Termination provision:  
- the circumstances in which the contract may be terminated by a party ahead of its scheduled expiry;  
- the payment (if any) that must be made by the Authority to the PPP Company upon termination (depending on the circumstances);  
- the condition of the assets when they are “handed over” to the Authority following termination.  

The typical grounds for termination are:  
- expiry of the PPP contract term;  
- default by the PPP Company;  
- default by the Authority;  
- a voluntary decision by the Authority; and  
- termination in the event of prolonged force majeure. |

**New Concepts:**

VoluntaryTermination;

(Concepts Payee and Payer are moved to Monetary Item viewpoint).

**New Tuples:**

EarlyTermination -- has type -- VoluntaryTermination;

**8.3.13 Request for Proposal and Proposal**

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Request for Proposal and Proposal contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank: Public-Private</td>
<td>RFP documents typically include the following: Commercial terms (Costs, Revenue)</td>
</tr>
</tbody>
</table>
| Partnerships Reference Guide, Version 2.0 (p 185) | Risk allocation Draft project agreements:  
- Performance Requirement  
- Payment mechanism and adjustments  
- Dispute resolution plan  
- Termination provision plan  
*Obtained permits or approvals*  
Technical information  
Bid rules, Bid instructions; Timetable  
*Bid bond*  
Bid evaluation criteria; |
|---|---|
| ESCAP: A Guidebook on Public Private Partnerships in Infrastructure (p 68) | RFP:  
- Technical conditions of the *project site*;  
- The *projected usage/demand for services*;  
- Relevant legal, technical, financial information;  
- Level and amount of service to be delivered;  
- Output standards/specifications;  
- Auxiliary tasks that may also be needed to be undertaken;  
- Safety/security standards;  
- payment mechanism and penalty regime,  
- Bid formalities, bid evaluation criteria and their relative weights;  
- Contents of the tender proposal with specified requirements to be met;  
Draft Contract:  
- Risk allocations and responsibilities of each party;  
- Financial terms (including *revenue sharing*, if any);  
- Performance standards, target dates, deliverables;  
- Options for terminating the contract;  
- Contract management procedures and mechanisms;  
- Dispute resolution approach and mechanisms. |
| South Africa: National Treasury PPP Manual - Module 5: PPP Procurement (pp 27-41) |  
- General information to bidders  
Project framework  
*Project assets*  
Procurement framework and timelines  
Instructions to bidders  
*Requirements related to third parties*  
Important definitions  
- Essential minimum requirements  
Financial;  
Legal; |
<table>
<thead>
<tr>
<th>Technical</th>
<th>Commercial Framework Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service specifications</td>
<td>duration of the project; project commencement and termination dates</td>
</tr>
<tr>
<td>Output specification</td>
<td>payment mechanisms</td>
</tr>
<tr>
<td>Specification of Indirect outputs</td>
<td>site issues</td>
</tr>
<tr>
<td>Input specifications</td>
<td>force majeure</td>
</tr>
<tr>
<td>Conditions of asset specifications</td>
<td>change in law</td>
</tr>
<tr>
<td>Standard specifications</td>
<td>modifications regime</td>
</tr>
<tr>
<td>Payment mechanism and penalty regime</td>
<td>termination and step-in rights</td>
</tr>
<tr>
<td>indivisible unitary payment</td>
<td>end of term arrangements</td>
</tr>
<tr>
<td>Indexation mechanism</td>
<td></td>
</tr>
<tr>
<td>Penalty mechanism</td>
<td></td>
</tr>
<tr>
<td>Legal requirements and draft PPP agreement</td>
<td></td>
</tr>
<tr>
<td>Commitments required from bidders</td>
<td></td>
</tr>
<tr>
<td>Evaluation criteria</td>
<td></td>
</tr>
<tr>
<td>Technical solution</td>
<td></td>
</tr>
<tr>
<td>Financial solution</td>
<td></td>
</tr>
<tr>
<td>Bid formalities</td>
<td></td>
</tr>
<tr>
<td>the time, place and manner of bid submission</td>
<td></td>
</tr>
<tr>
<td>formal processes for communication with bidders</td>
<td></td>
</tr>
<tr>
<td>bid bonds</td>
<td></td>
</tr>
</tbody>
</table>

Australia: National PPP Guidelines Volume 2: Practitioners' Guide (pp 17-23)
Project management:
Commercial: (consortium structure; equity structure; third-party revenue opportunities)
Financial: (Funding Structure)
Interface management; (Communication methods)
Risk-adjusted cost
Output specification
functional brief
architectural specification
technical specification
furniture, fittings and equipment (“FF&E”) specification
services specification

Public Sector Comparator

World Bank - PPIAF: How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets
(p 123)

RFP:
output specifications;
payment mechanisms;
risk allocation,
model designs and plans;
detailed background information
Bid process,
evaluation criteria,
timetable

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| EPEC: The European PPP Expertise Centre (EPEC), PPP Guide (p 23) | PPP draft contains:
  - the rights and obligations of the parties;
  - risk allocation;
  - service performance standards and targets;
  - technical design;
  - the procedure for permitted modifications;
  - payment mechanisms;
  - penalties (and possibly bonuses) which have financial consequences or give rise to warning notifications (eventually leading to termination of the PPP contract);
  - security and performance bonds;
  - project insurances; |
**India: Public Private Partnerships in India: toolkit**

(Module 2, Phase 3, Contents of the RFP)

- General instructions to bidders;
- Output-focused specification;
- *Site-specific details*;
- Financing requirements;
- Environmental and social safeguard requirements;
- Payment mechanisms
- Risk allocation
- Performance standards covering all stages in the life of the PPP
- Penalties for under-performance
- The intended risk allocation
- Roles, rights, responsibilities and restrictions of all parties
- Key schedules to the Agreement
- *Site description*
- Specifications and standards
- Required tests and inspections, and procedures for testing, independent inspections, and reporting
- Schedule of user fees/ tariff rates
- Financial arrangements, such as performance security, *escrow accounts*
- Substitution agreement (in case of financial default by the concessionaire)
- Criteria for bid evaluation

**New Concepts:**

SiteSpecification; BidBond; DesignOption (already exists in the metamodel)

**New Tuples:**

(Proposal, RequestForProposal) -- has part -- (SiteSpecification; BidBond; DesignOption;)

BiddingInstruction -- has part -- BidBond;

**8.3.14 Bid Evaluation**

<table>
<thead>
<tr>
<th>Source</th>
<th>Extracted Concepts: Bid Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank: Public-Private Partnerships Reference Guide, Version 2.0</td>
<td>Basis for Award:</td>
</tr>
<tr>
<td></td>
<td>Selection based on financial criteria: Technical proposal assess (Pass, Fail)</td>
</tr>
<tr>
<td></td>
<td>Selection based on financial and technical criteria: Weighted combination of Financial and Technical criteria</td>
</tr>
<tr>
<td>Source</td>
<td>Criteria/Methods</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>(p 179, 188)</td>
<td>financial criterion: Tariff; Costs; Least Present Value of Revenue; concession length; Investment amount; technical evaluation: proposal -- complies to -- output specification</td>
</tr>
</tbody>
</table>
| World Bank: Concessions for infrastructure - A guide to their design and award (pp 118, 119) | - Weighted evaluation method:  
  Investment plan;  
  Promised additional investments;  
  Organizational plan;  
  Maintenance plan;  
  *Concession fee* to be paid;  
  Payment required by the users;  
  *Number of personnel retained from Public company*  
  - Financial evaluation method:  
    The Highest *Concession fee*, to be paid to Government;  
    The highest price, to be paid for the assets (*asset price*)  
    The lowest cost to the government for constructing or operating facilities or services;  
    The largest amount of new investment to be undertaken by the operator.  
    The lowest tariff to be charged to consumers.  
    The lowest net present value of the future revenue stream to the developer from the service or project.  
    The lowest subsidy that the government must provide to the winning bidder to operate a loss-making service. |
| Australia: National PPP Guidelines Volume 2: Practitioners' Guide (p 62) | - Value for money and the PSC:  
  Costs and Risk allocation  
  - Commercial and Financial criteria:  
    Financing structure; *Finance reliability*; Equity support; performance based payments and bonus; Debt and interest rate; *Tax assumptions*;  
  - Design evaluation issues  
    Functionality of design; Performance specifications; The *flexibility* of the proposed solution  
  - Service delivery evaluation:  
    *Service delivery management*  
    *Impact of enabling services* on the core services |
| QLD, Australia: Public private partnerships guidance material, Supporting | Evaluation Criteria:  
  A comparison of the whole-of-life cost with the public sector comparator. |
| document | The approach to delivery of the output specification  
The technical solution being proposed;  
The proposed commercial approach, including the risk allocation |
|----------|---------------------------------------------------------------------------------------------------|
| South Africa: National Treasury PPP Manual - Module 5: PPP Procurement (pp 45-51) | - Technical Evaluation:  
Development phase:  
• Design evaluation (extent, quality, safety, cost effectiveness, functionality and innovation of designs)  
• Robustness of cost estimates  
• Impact on social and biophysical environment  
• Deliverability and time schedules  
• Integration of design, development and operations  
• Quality management systems  
Delivery Phase:  
• Performance targets and measurement systems exceed minimum specifications  
• Quality and type of proposed services to end users  
• Asset management philosophy  
• Quality of proposed management structure, (staffing, systems and practices)  
• Quality and extent of proposals on branding, promotion and public relations  
• Quality of safety plans  
• Integration of PPP with existing services  
• Integration of PPP information into existing IS system  
• Compliance with institution’s monitoring and reporting requirements  
- Financial solution  
• Total project cost in relation to the affordability constraints of the PPP  
• Realism of operating and capital expenditure  
• Robustness of the financial proposals  
• Robustness of the funding structure  
• Level and nature of equity in the funding structure |
• Level of commitment demonstrated by the debt and equity providers
• Cost, level and nature of insurance cover
• Risk allocation: the risk profile proposed by bidders

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| EPEC: The European PPP Expertise Centre (EPEC), PPP Guide (p 23) | • the lowest tariffs, service fee or level of grant or subsidy;  
• the largest payments to the Authority (upfront or periodic);  
• the shortest duration of the PPP contract; and  
• the best promised performance, expressed as key objective indicators year by year. |
| World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT (pp 172, 173) | Technical evaluation criteria:  
• Strength and deliverability of the financing plans  
• Degree of commitment from equity and debt providers  
• Degree of acceptance of underlying contract terms and associated risk allocation.  
Financial evaluation criteria:  
• Customer or operator tariff required  
• Upfront fee, periodic lease payments, or concession payment to the contracting authority  
• Price for shares or assets to be sold  
• Capital investment committed by the operator  
• Coverage (or new connection) targets  
• Service or management fees payable to the operator  
• Subsidy payable by the contracting authority. |

New Concepts:

ConcessionFee; FinancierDegreeOfCommitment (this concept is moved to Finance Structure Viewpoint).

New Tuples:

FinancialCriteria -- has type -- ConcessionFee;

8.3.15 Contract Management
PPP Management:
Contract Management Structure (Responsibilities)
- Monitoring
- Change Management
- Contract Expiry Management

Management responsibility -- requires -- skill

Five key skills (Skill types):
Communication; negotiation; change management; financial competence; analytical skills.

- Monitoring:
  Performance monitoring
  Compliance monitoring
  Risk Monitoring

Performance monitoring -- collects -- monitoring data
Monitoring data -- has type -- Service users; private party reports
Performance -- assessed by -- KPI
Performance monitoring -- specifies -- consequences for failure

Risk monitoring -- identifies -- Emergent risks
Risk monitoring -- plans -- Disaster management strategy
Disaster management strategy -- has type -- Incidence response; Mitigation strategy; Recovery strategy

- Change Management
Adjustment -- has type -- price adjustment; output requirement adjustments; Dispute resolution; Renegotiations

- Contract expiry management:
Parts: Asset Handover; Expiry payment

Asset Handover -- has part -- Asset quality assessment; asset handover payment
Asset quality assessment -- has parts -- Asset; KPI

Key aspects of Contract management:
<table>
<thead>
<tr>
<th><strong>Infrastructure</strong> (pp 72-74)</th>
<th></th>
</tr>
</thead>
</table>
| **Contract administration**  
Service delivery management  
Relationship management  |
|  
- Contract administration: variation management, *maintaining the integrity of the contract*, financial administration  
- Service delivery management:  
Risk management  
Performance management  |
| Risks management -- controls risk -- by appropriate actions  
Performance management -- ensures -- quality and quantity of service  |
| **Main tasks of contract management:**  |
|  
- Management roles and responsibilities  
- Monitoring of *project delivery* (*Construction phase*)  
- Management of variations  
- Monitoring of operational aspects and service outputs  
- *Fiscal obligations of the government*  
- Redressal of public grievances  
- Compliance with reporting requirements  |
| Monitoring framework -- has -- Information requirements; performance indicators  
Reporting requirements -- provide -- report template  |

<table>
<thead>
<tr>
<th><strong>Australia: National PPP Guidelines Volume 2: Practitioners’ Guide</strong> (p 131)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contract management:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Performance management  
  • Monitor private party’s performance  
  • Seek user feedback  
- Relationship management  
  • Maintain and strengthen communication  
  - Change management  
    • *Changes to output specifications*  
    • Automatic contractual changes (indexation of payments)  
    • *Changes in service requirements and technology*  
    • Manage asset transfer  
  - Managing contingency events  
    • Maintain and review contingency plans  
    • Scan environment for potential impacts  
    • Respond to defaults and disasters  |

<table>
<thead>
<tr>
<th><strong>European Commission:</strong></th>
<th>Contract management:</th>
</tr>
</thead>
</table>
Guidelines for Successful Public-Private-Partnerships (pp 93-97)

- Performance Management
- Project Agreement
- Relationship Management
- Quality Monitoring
- Dispute Resolution Procedures

Management structure -- has --roles and responsibilities
Roles -- require -- skills

Monitoring ( quality monitoring; financial consequences of under-performance)

Risk management;

Change management (technical developments, changes in law, changes in volumes and changes in Contracting Authority requirements)

Validation Table:

<table>
<thead>
<tr>
<th>Source</th>
<th>Compared Concepts:</th>
</tr>
</thead>
</table>
| PPIAF: The Toolkit for Public-Private Partnerships in Roads and Highways (Module 5, p 121) | Contracting Authority is responsible for managing the concession agreement in order to:
• Ensure compliance with laws and regulations
• Ensure delivery of contracted services
• Ensure asset management
• Deal with performance variations
• Ensure and maintain Value for Money
• Handle and resolve disputes
• Ensure proper transfer of ownership of assets
• Manage contract negotiations

Contract Management covers the following key provisions:
• Monitoring compliance in all phases
• Managing the Agreed Risk Allocations
• Management of Change
• Dealing with Under Performance (of any partner) |
| Hong Kong: An Introductory Guide to Public Private Partnerships (PPPs) (p 62) | Contract Manager roles:
Oversee the design and construction phases
Monitor the project once it becomes operational
Establish and manage the day to day relationship with the consortium
Keep abreast of developments in the field covered by the project and consider the need for change
Manage the agreement of any changes during the life of the contract |
Monitor the achievement of key performance indicators
Recommend and calculate payments/abatements
*Report* regularly to the PSCom
Advise the PSCom of any serious performance failures and the need for dispute resolution measures to be initiated.

**World Bank, PPIAF: Approaches to Private Participation in Water Services, A TOOLKIT**

Contract Management Tasks:
- Monitoring operator’s performance
- Enforcing operator’s performance
- Monitoring contracting authority’s performance
- Enforcing contracting authority’s performance
- Resolving disputes
- Adjusting tariffs
*Adjusting service standards*
- Maintaining good relations

**India: Public Private Partnerships in India: toolkit**

Contract Management Stages:
- Pre-Operation Stage:
  - Private Party brings the project to Financial Closure

  **Construction Stage:**
  - checking that works will be completed on time

  **Operation Stage:**
  - Monitoring the main outputs and services;
  - *Review the monitoring process* conducted by Private Party;

  **Contract Closure and Asset Transfer:**
  - Monitoring the asset condition;
  - Ensuring that the necessary records, documents and legal titles are provided and correctly transferred.

**New Concepts:**

- ServiceRequirementAdjustment; ConstructionMonitoring;

**New Tuples:**

- Adjustment -- has type -- (ServiceRequirementAdjustment; ServicePriceAdjustment)
- ContractComplianceMonitoring -- records -- ContractualIssue;
- Monitoring -- has type -- ConstructionMonitoring;

**8.4 Appendix 4: Graphical Drawings of the Viewpoints**

**8.4.1 PPP Functions and Roles**
Figure 8-1: PPP Functions and Roles viewpoint v1.0

Figure 8-2: PPP Functions and Roles viewpoint v1.1

8.4.2 Financing Structure
8.4.3 Project Costs
Net Present amount = \( \text{Sum} \left( \frac{\text{Yearly Value}}{(1+\text{Discount rate})^t} \right) \) for \( n \) years;

Net Present amount (complex Cost) = \( \text{Sum} \left( \text{Net Present amount (contained Costs)} \right) \)

**Figure 8-5: Project Costs viewpoint v1.0**
8.4.4 Project Risks
8.4.5 Risk Assessment and Management
Sum (Probability of Risk States) = 100%

Cost of Risk = Sum (Risk State Cost)
Risk State Cost = Risk Base Cost * Consequence Impact * Probability;

Net Present amount = Sum (Yearly Value / (1+Discount rate) ^ t) for n years;
Net Present amount (complex Risk) = Sum (Total Net Present Value (contained Risks))

Figure 8-9: Risk Assessment and Management viewpoint v1.0

Sum (Probability of Risk States) = 100%

Cost of Risk = Sum (Risk State Cost)
Risk State Cost = Risk Base Cost * Consequence Impact * Probability;

Figure 8-10: Risk Assessment and Management viewpoint v1.1
8.4.6 Feasibility Assessment

Figure 8-11: Feasibility Assessment viewpoint v1.0

Figure 8-12: Feasibility Assessment viewpoint v1.1

8.4.7 Financial Assessment
Figure 8-13: Financial Assessment viewpoint v1.0
Project Internal Rate of Return:
\[ \sum (R_i - I_i - C_i) / (1+r)^i = 0; \]
R_i is the operating revenue at year i
I_i is the amount invested at year i
C_i is the operating cost at year i

WACC = \( \frac{E}{V} \)Re + \( \frac{D}{V} \)Rd (1-Tc);
Re = cost of equity
Rd = cost of debt
E = market value of the firm’s equity
D = market value of the firm’s debt
V = E + D
E/V = percentage of financing that is equity
D/V = percentage of financing that is debt
Tc = corporate tax rate

8.4.8 Value for Money Assessment
PSC = Raw PSC + Transferred Risks + Retained Risks

NPC of Bidder = Bid Price + Retained Risks;

Raw PSC = Raw Costs – third-party revenue

Transferred Risks = Risks transferred to the private party

Retained Risks = Risks retained by the public sector

Total Value of Retained and Transferred Risks = Sum (Total Value of aggregated Risks)

**Figure 8-15: Value for Money Assessment viewpoint v1.0**
PSC = Raw PSC + Transferred Risks + Retained Risks + Competitive Neutrality;

Competitive Neutrality = Public Sector Advantages – Public Sector Disadvantages;

NPC of Bidder = Bid Price + Retained Risks;

Raw PSC = Raw Costs – Third-party revenue

Transferred Risks = Risks transferred to the private party

Retained Risks = Risks retained by the public sector

Total Value of Retained and Transferred Risks = Sum (Total Value of aggregated Risks)

Figure 8-16: Value for Money Assessment viewpoint v1.1

8.4.9 Output Services
Figure 8-17: Output Services viewpoint v1.0

Figure 8-18: Output Services viewpoint v1.1
8.4.10 Payment Mechanism

8.4.11 Dispute Resolution Mechanism
8.4.12 Contract Termination Management
8.4.13 Request for Proposal and Proposal
8.4.14 Bid Evaluation
8.4.15 Contract Management
8.4.16 Monetary Items
Net Present amount = Sum (Yearly Value / (1+Discount rate) ^ t) for n years;
or
Net Present amount = Sum (Yearly Value / (1+Nnominal Discount rate) ^ t) for n years;
Nominal discount rate = (1 + real discount rate) x (1 + inflation rate) - 1;

Net Present Value (complex Item) = Sum (Total Net Present amount (contained Items))
Total amount (Complex Item) = Sum (Total Amount (Contained Items))

Figure 8-31: Monetary Items viewpoint (only in v.1.1)

8.5 Appendix 5: Concepts and Definitions

Table 8-9: List of all PMM Concepts

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>EngineeringOrganization</th>
<th>ProposalRank</th>
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<tr>
<td>Amount</td>
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<td>RequestForProposalAndProposalViewpoint</td>
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Table 8-10: Concept Definitions

<table>
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<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Arbitration</td>
<td>One of the alternative disputes resolution methods in which the parties to an agreement entrust the resolution of their disagreements to an arbitral tribunal composed of one or three arbitrators chosen by them, rather than to a tribunal or court of the State judiciary system.</td>
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<tr>
<td>Bankability</td>
<td>A feature of the project which is being likely to be considered eligible for bank funding, having an acceptable allocation of risks, a competitive return on equity for the sponsors and which maintains the required minimum debt cover ratios for the lenders.</td>
</tr>
<tr>
<td>BidBond</td>
<td>Means an obligation by a third party to guarantee that a party awarded a contract will accept the award in case a binding decision is full and final (such as an arbitral award).</td>
</tr>
<tr>
<td>BidPrice</td>
<td>The price offered by a bidder.</td>
</tr>
<tr>
<td>CapitalCost</td>
<td>Long-term expenditures for plant and equipment.</td>
</tr>
<tr>
<td>CommercialRisk</td>
<td>Relate to the possibility that the project cannot generate the expected revenue because of changes in market prices or demand for the goods or services.</td>
</tr>
<tr>
<td>CompensationOnTermination</td>
<td>Those amounts that a Concession Agreement specifies as due when a concession is terminated prematurely.</td>
</tr>
<tr>
<td>CompetitiveNeutrality</td>
<td>Competitive Neutrality adjustments remove any net advantages (or disadvantages) that accrue to a government business simply by virtue of being owned by government.</td>
</tr>
<tr>
<td>ConcessionFee</td>
<td>A payment made by the Operator to the Contracting Authority in a Concession.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CoreService</td>
<td>For social infrastructure, those services for which governments have particular responsibilities to people using the service and the community (e.g. hospitals, schools, etc.). For economic infrastructure, services included in this definition will be determined on a case-by-case basis.</td>
</tr>
<tr>
<td>CorporateGuarantee</td>
<td>is an accessory contract (payable amount) by which a person (promisor) undertakes to be answerable to the person to whom the promise is given (promisee) for the default of another person’s contractual obligations to the promisee.</td>
</tr>
<tr>
<td>CorporateTax</td>
<td>CorporateTax is a tax on the income or capital of corporations or analogous legal entities.</td>
</tr>
<tr>
<td>CostOfFinance</td>
<td>The rate of return required by providers of capital (debt and equity).</td>
</tr>
<tr>
<td>Default</td>
<td>failure to comply with one’s contractual obligations such as for example under a loan agreement, the failure to make timely payment of interest or principal on a debt or to otherwise comply with provisions of the loan agreement.</td>
</tr>
<tr>
<td>DemandRisk</td>
<td>Risk arising from the variation of output or capacity from expected.</td>
</tr>
<tr>
<td>DiscountRate</td>
<td>A percentage rate representing the rate at which the value of equivalent benefits and costs decrease in the future compared to the present. This rate used to calculate the present value of future cash flows.</td>
</tr>
<tr>
<td>ExchangeRate</td>
<td>The price at which one currency trades for another.</td>
</tr>
<tr>
<td>ExchangeRateRisk</td>
<td>The risk that a long or short position in a foreign currency will have to be closed out at a loss, due to an adverse movement in the relevant exchange rate.</td>
</tr>
<tr>
<td>FinanceCostOverrunRisk</td>
<td>Risk caused by unpredictable variation in interest rates and in other terms and conditions of financing, including its availability.</td>
</tr>
<tr>
<td>ForceMajeure</td>
<td>Acts of God and other specified risks (e.g. terrorism) which are beyond the control of the parties to the contract and as a result of which a party is prevented from or delayed in performing any of its non-financial obligations under the contract.</td>
</tr>
<tr>
<td>InterestRateRisk</td>
<td>Risk caused by unpredictable variation in interest rates.</td>
</tr>
<tr>
<td>Mediation</td>
<td>Refers to one of the alternative disputes resolution methods in which a person assists the parties in an independent and impartial manner in their attempt to reach an amicable settlement of their dispute.</td>
</tr>
<tr>
<td>MonitoringUnit</td>
<td>A body set up by the Contracting Authority to monitor whether the Operator is meeting its obligations under the Arrangement.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
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</tr>
<tr>
<td>NetPresentAmount</td>
<td>The present value of the expected cash flows associated with a project after discounting at a rate which reflects the value of the alternative use of the funds so as to enable comparison between options with different cashflow profiles.</td>
</tr>
<tr>
<td>NominalDiscountRate</td>
<td>In finance and economics nominal discount rate refers to the rate of discount before adjustment for inflation (in contrast with the real discount rate).</td>
</tr>
<tr>
<td>OperationAndMaintenanceCost</td>
<td>Expenditures of running and maintaining assets.</td>
</tr>
<tr>
<td>Operator</td>
<td>The private, partly private, or foreign-state-owned company providing services under an Arrangement.</td>
</tr>
<tr>
<td>PerformanceBond</td>
<td>A performance bond commits the bonding company (or a bank) to step in and complete the contract if the consortium defaults on the contract. The bonding company may complete this either by performing the work itself, or by obtaining bids for the balance of the work, and then paying for the balance of the work up to the total amount of the bond.</td>
</tr>
<tr>
<td>ProjectCosts</td>
<td>The costs associated with design, construction, operation, maintenance and refurbishment of the infrastructure over the term of the project.</td>
</tr>
<tr>
<td>PublicAuthority</td>
<td>The local, provincial, or national authority that contracts with, or issues a License to, the Operator, and which typically designs aspects of the Arrangement, selects the Operator, and monitors aspects of its performance.</td>
</tr>
<tr>
<td>PublicSectorComparator</td>
<td>The hypothetical, risk-adjusted whole-of-life cost of a public sector project if delivered by government</td>
</tr>
<tr>
<td>RawPSC</td>
<td>The base cost to government of producing and delivering the reference project. It does not include any allocation of value for risks and contingencies that may affect cash flows.</td>
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<tr>
<td>Regulator</td>
<td>A specialist agency of the Government responsible for controlling the Tariff and customer service standards and for monitoring and enforcing the performance of the operator.</td>
</tr>
<tr>
<td>RegulatoryAndPoliticalRisk</td>
<td>Risk caused by unpredictable government action or inaction (for example, expropriation, change of law, cessation of convertibility of the currency, and failure to permit a contractually agreed tariff increase).</td>
</tr>
<tr>
<td>RequestForProposal</td>
<td>A request for proposal issued by government for a project</td>
</tr>
<tr>
<td>RetainedRisks</td>
<td>The value of those risks or parts of a risk that government bears under a PPP project</td>
</tr>
<tr>
<td><strong>Risk</strong></td>
<td>Risks relate to the exposure to a peril, the occurrence of events and their consequences that differ, either positively or negatively, from those that were assumed (or not, as the case may be) in establishing a project. Risks are often categorised as strategic, financial, operational and hazard risks. They arise in all projects, irrespective of the approach adopted.</td>
</tr>
<tr>
<td><strong>Risk Allocation</strong></td>
<td>The allocation of responsibility for dealing with the consequences of each risk to one of the parties to the contract; or alternatively, agreeing to deal with a particular risk through a specified mechanism which may involve sharing that risk.</td>
</tr>
<tr>
<td><strong>Risk Management</strong></td>
<td>The identification, assessment, mitigation and monitoring of risks associated with a project. The aim is to reduce their variability and impact.</td>
</tr>
<tr>
<td><strong>Step In Right</strong></td>
<td>Rights relevant to both the private and the public sectors. In the case of the private sector, step-in rights will be a matter for the Direct Agreement between financiers, the client department and the consortium.</td>
</tr>
<tr>
<td><strong>Subsidy</strong></td>
<td>A form of financial assistance or support from government paid to a business or economic sector used to support businesses that might otherwise fail, or to encourage activities that would otherwise not take place.</td>
</tr>
<tr>
<td><strong>Tariff</strong></td>
<td>The price customers pay for services.</td>
</tr>
<tr>
<td><strong>Transferred Risks</strong></td>
<td>The value of those risks (from government’s perspective) that are likely to be allocated to the private party under a PPP project.</td>
</tr>
<tr>
<td><strong>Weighted Average Cost of Capital</strong></td>
<td>The average weighted rate that a company pays for its capital, comprising debt and equity. WACC is the minimum return (or target) that a company must earn on its capital to satisfy its creditors, owners, and other providers of capital.</td>
</tr>
</tbody>
</table>
References


4. Department of Infrastructure and Transport, *Infrastructure Planning and Delivery: Best Practice Case Studies Volume 2*, Infrastructure and Transport, Editor. 2012, Department of Infrastructure and Transport


30. Esther Cheung, *Developing a Best Practice Framework for Implementing Public Private Partnerships (PPP) in Hong Kong*, in *School of Urban Development, Faculty of Built Environment and Engineering*. 2009, Queensland University of Technology.


58. Sheila Block, *From P3s to AFPs: New Branding but Same Bad Deal*. 2008: Ottawa: Canadian Centre for Policy Alternatives.


65. Jake Rupert, *Ring Partnerships are Failing*, The Ottawa City, Editor.


84. World Bank, *Public-Private Partnerships Reference Guide: Version 2.0*. 2014: [http://api.ning.com/files/Iumatxx-0jz3owSB05xZDkmWIE7GTYYA3cXwt4K4s3Uy0NtPPRgPWY0j1Lea7uqybQeTX1euSUybPF61ysuyN5rL6b2Ms/PPPReferenceGuidev02Web.pdf](http://api.ning.com/files/Iumatxx-0jz3owSB05xZDkmWIE7GTYYA3cXwt4K4s3Uy0NtPPRgPWY0j1Lea7uqybQeTX1euSUybPF61ysuyN5rL6b2Ms/PPPReferenceGuidev02Web.pdf).


156. Marcos Arjona, Carolina Dania, Marina Egea, and Antonio Maña, *Validation of a security metamodel for development of cloud applications*, in *Workshop on Quantitative Approaches to Object-Oriented Software Engineering (QAOOSE 2010)*. 2010: Malaga, Spain.


186. Department of Human Services Victoria; and Department of Treasury and Finance Victoria; *The new Royal Children’s Hospital Project*. 2008.