PCA-MIMOSA Reference Architecture Framework for Integrated Engineering and Operations

VERSION 1.0

Owner: PCA, MIMOSA

Project: IT Architecture SIG

Authors: Frode Myren (IBM), Tore Christiansen (PCA), Nils Sandsmark (PCA), Avin Mathew (MIMOSA), Alan Johnston (MIMOSA)

Document History

Document Location

This is a snapshot of an online document. Paper copies are valid only on the day they are printed. Refer to the authors if you are in any doubt about the currency of this document.

This document is located at https://www.posccaesar.org/wiki/SigIT

Revision History

Revision Number	Revision Date	Summary of Changes
1.0	2013.11.11	First official version

Summary

In this document we introduce the Reference Architecture Framework (RAF) for Integrated Engineering and Operations for POSC Caesar Association (PCA) and MIMOSA, and show how it can be used for defining new IT applications, as a guide for designing IT systems, as well as a classification system for describing existing IT infrastructure in the upstream Oil & Gas industry, downstream Petrochemical industry, and for Engineering Procurement Construction projects.

The Reference Architecture is defined in terms of a general architecture, which defines a given system by a set of dimensions and set of models that each describes a specific set of system design issues and collectively illustrate the concerns of all involved stakeholders. Since the purpose of our architecture is to address several aspects of IT systems, our choice of dimensions has been made in order to allow description in terms that are important to both business and technical capabilities of integrated IT infrastructures. The dimensions are meant to cover a complete set of production systems, control systems and information systems in terms of system configuration, context and content:

(1) The Business Context dimension is used to describe scope and focus used in order to realize the system configuration and content according to the PISTEP Engineering Activity Model (PEIM) and the OpenO&M ISBM Specification in the Oil and Gas Interoperability (OGI) Pilot Use Cases, which support the ISO TC 184 OGI Technical Specification project in the Joint MIMOSA/PCA Special Interest Groups (SIGs). This constitutes the description of "*what business*" the system addresses.

(2) The Information Content dimension is used to describe knowledge representation and references according to the ISO 15926 Reference Data Library (RDL) and operations and maintenance (O&M) object/event instantiations according to MIMOSA's Common Conceptual Object Model (CCOM). This constitutes the description of "*what knowledge*" the system formalizes.

(3) The Technology Configuration dimension is used to describe system lay-out and structure according to the widely recognized Purdue Enterprise Reference Architecture (PERA). This constitutes the description of "*what technology*" the system contains.

Based on the above dimensions we use a set of models to define, design and describe different types of system characteristics, including a Service Agreement Model, a System Engineering Model, a Software Interoperability Model, a Semantic Ontology Model, and a Standards Utility Model.

Our goal is to create a common unifying framework which conveys a high level description of the information technology architecture. We also give a set of examples of how our framework

can be used as a basis for specifying architectural choices made in concrete implementation projects.

Table of Contents

1 Introduction and Motivation

For many decades standardization efforts have sought to unify and simplify the way in which we can use computers to represent how we define, describe and reason about complex technical systems for operation and optimization of industrial production. Thus a large number of technical standards and architecture frameworks exist for production systems, control systems and information systems with different focus and lifecycle perspective and in various industries.

In an attempt to address the above “standards challenge” POSC Caesar Association (PCA) and MIMOSA have agreed to describe a common Reference Architecture Framework - as a guideline and checklist for defining, designing and describing the architectural choices made for both new and existing IT infrastructures where these standards are relevant.

This document presents a principled approach to architectures by defining and describing:

- A high level reference architecture and set of reference models.
- A set of architecture dimensions representing Business Context, Information Content and Technology Configuration.
- A set of models covering service agreements, systems engineering, software integration, semantics ontology and standards usage.
- A series of architecture examples from actual systems in various industries.

PCA is a non-profit global-standardization member organization that promotes development of open specifications to be used as standards for enabling interoperability of data, software and related services. PCA initiated ISO 15926 “Integration of lifecycle data for process plants including oil and gas production facilities" and is committed to its maintenance and enhancement.

MIMOSA is a not-for-profit trade association dedicated to developing and encouraging the adoption of open information standards in manufacturing, fleet, and facility environments. MIMOSA provides a series of interrelated information standards for O&M. The Common Conceptual Object Model (CCOM) provides in Unified Modeling Language (UML) an object model for all O&M content, while the CCOM-ML XML Schema provides the language to format and exchange enterprise O&M information. MIMOSA also manages the Intellectual Property for the OpenO&M Initiative, and the OpenO&M Information Service Bus Model specification provides supplier neutral connectivity for Purdue Model layer 3.

This report is a result of joint work with other Special Interest Groups (SIG) and standards organizations to develop a common IT Architecture, including:

- The joint Operation & Maintenance (O&M) SIG to develop pilots associated with the OpenO&M Use Cases.

- The various standardization organizations participating in the Standards Leadership Council (SLC)[1] on alignment across standards.
- Various member companies that participated and contributed information about their application examples and use cases.

The report is organized as follows:

- Section 2 introduces the Reference Architecture Framework with its Reference Architecture Dimensions and (RAD) and Reference Models (RM).
- Section 3 outlines the system Characteristics of the various RMs, and explains how the models are based on existing frameworks, paradigms, standards and practices.
- Section 4 lists a set of Reference Architecture examples and summarizes how they can be seen as instances of the RADs and selected RMs.
- Section 5 outlines the work to needed extend the current framework into a complete Architecture Methodology and Framework.
- Appendix A through Appendix E contain figures showing selected parts (Reference Model instances) from the Application Architecture examples listed in Section 4.
- Finally, Appendix F gives a summary list of relevant standards and frameworks.

[1] http://www.oilandgasstandards.org

2 The Reference Architecture

In order to address the needs of as many involved stakeholders as possible, the architecture has been structured into distinct Reference Architecture Dimensions (RADs) and a set of Reference Architecture Models (RMs), each describing the system from a particular viewpoint. This section outlines the overall structure of the RA in Section 2.1, and explains the content of and connection between its RADs in Section 2.2 to 2.4. The various RMs are described in Section 3.

2.1 The Reference Architecture Framework and Dimensions

The current Reference Architecture Framework (RAF) is meant to be used to classify application architectures and models, as a basis for (1) describing application architectures, (2) deriving implementation plans and (3) understanding existing information models.

Figure 2.1 illustrates how the RAF consists of a set of Reference Models (RM) structured around a set of Architecture Dimensions, designed and described to reflect various types of operational requirements.

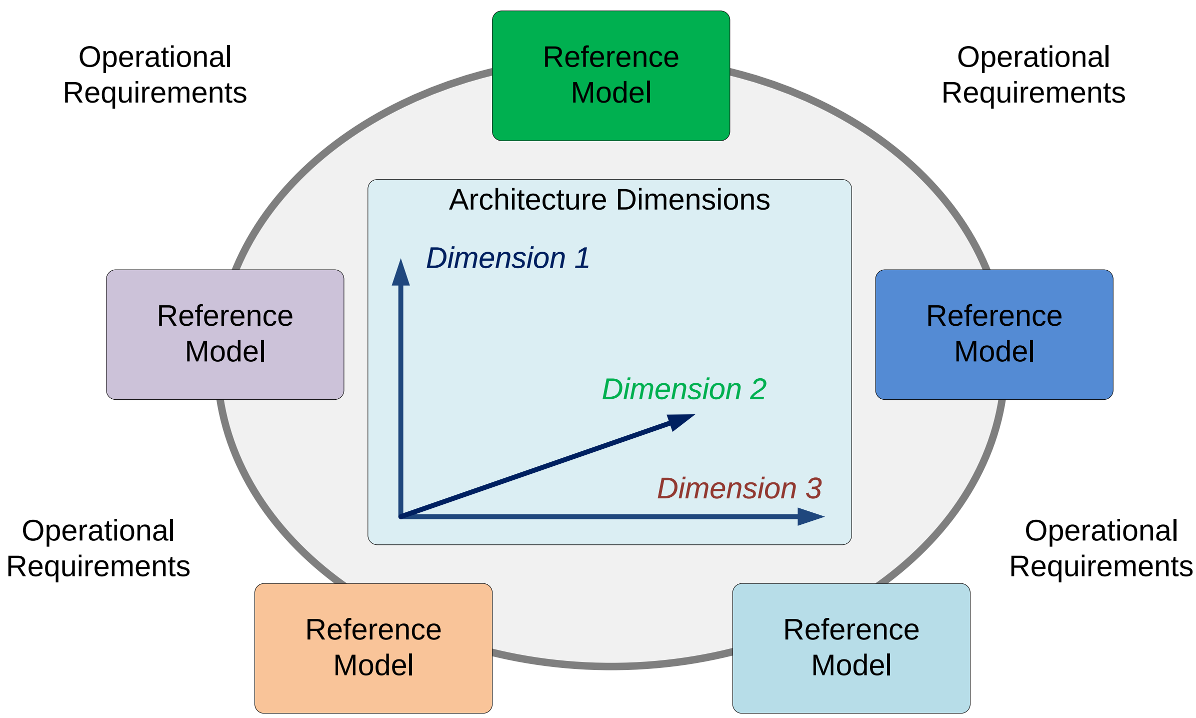

Figure 2.1: Reference Architecture Framework structure

The Architectural Dimensions of RAF include the Business Context dimension describing *what business*” the system addresses, the Information Content dimension describing “*what knowledge*” the system formalizes, and the Technology Configuration dimension describing "*what technology*" the system contains. These are key parts of designing, planning, implementing, and governing an enterprise.

Figure 2.2 shows the RAF, with Architecture Dimensions and Reference Models.

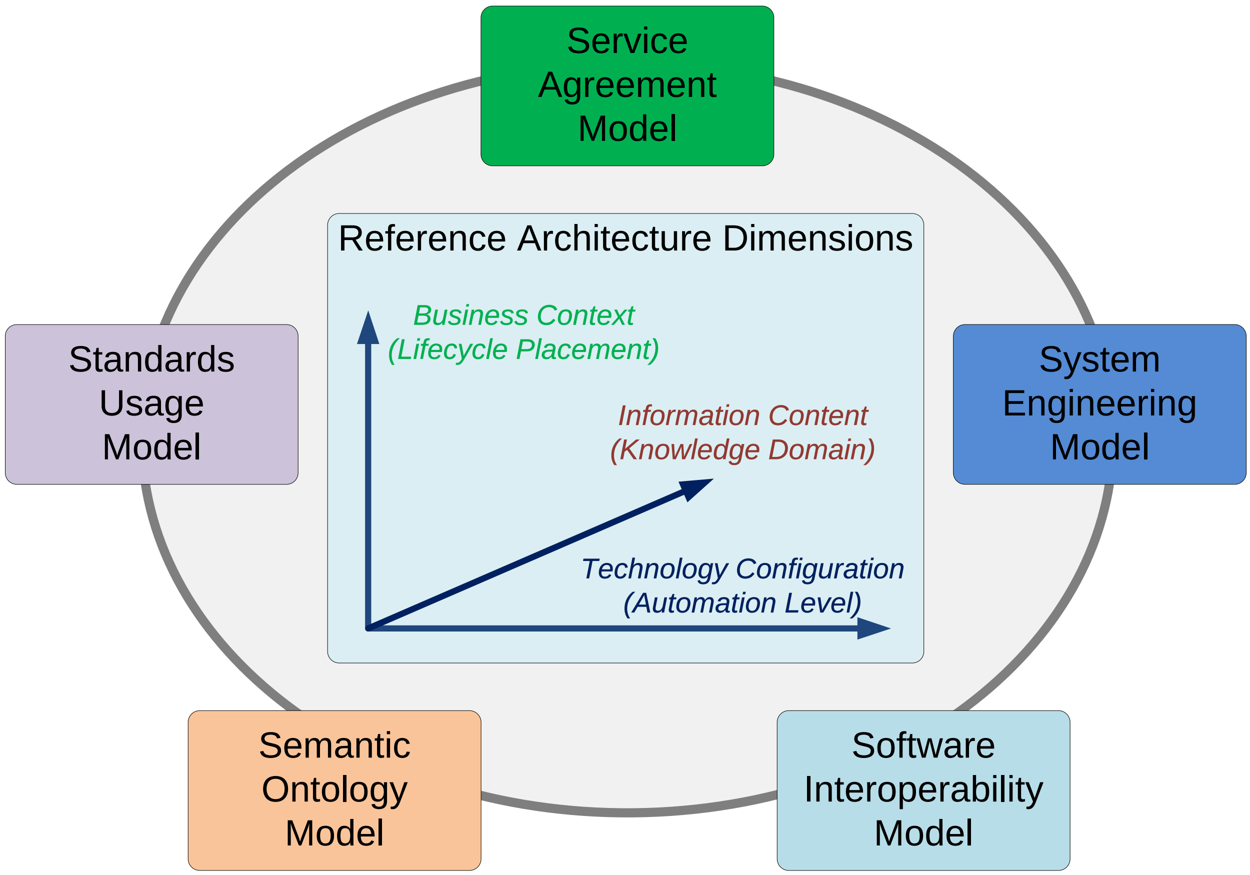

Figure 2.2: The PCA-MIMOSA Reference Architecture Framework

This holistic balance between business application, system configuration and operational implementation perspectives is also embodied in The Open Group Architecture Framework (TOGAF) Architecture Development Method illustrated in Figure 2.3 and Figure 2.4.

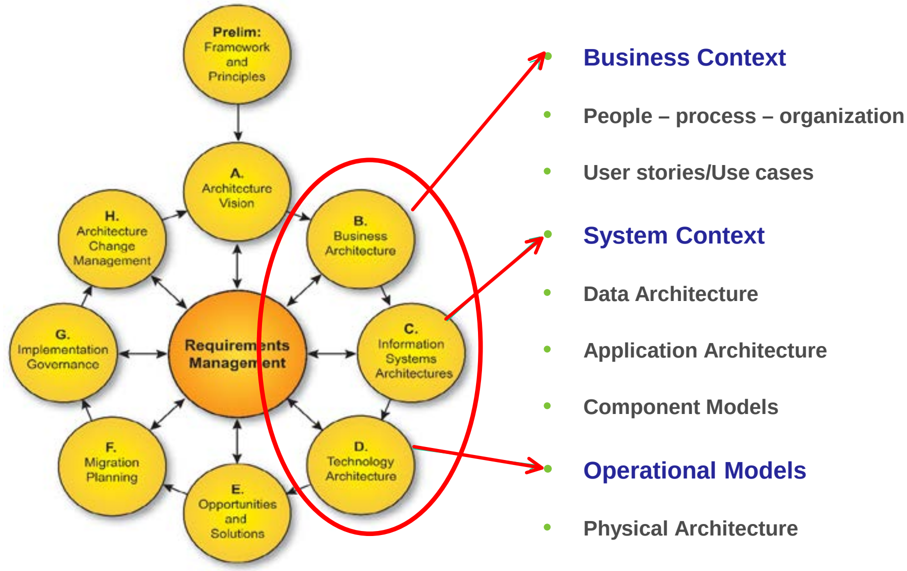

Figure 2.3: The TOGAF Architecture Development Method

Figure 2.4 illustrates the relationship between TOGAF Architecture Development Method and the PCA-MIMOSA RAF Architecture Dimensions and Reference Models, including aspects of lifecycle (business architecture), knowledge (information architecture) and technology (application architecture).

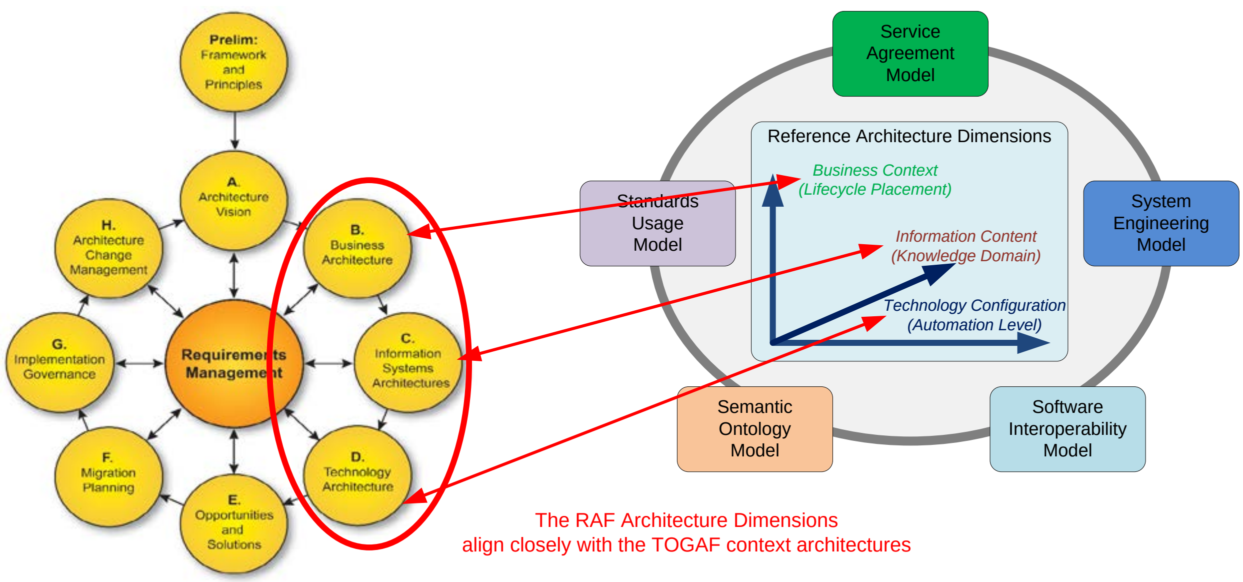

Figure 2.4: The RAF Corresponds to the TOGAF Architecture Framework

With the above outline of the structure and contents of the RAF, the frameworks used for each of the three architectural dimensions are introduced in the three sections below.

2.2 The Business Context

Figure 2.5 shows the Business Context dimension of the architecture framework, which describes the spatial and temporal context based on the PISTEP Engineering Life-cycle Activity Model with its standard set of process and engineering activities.

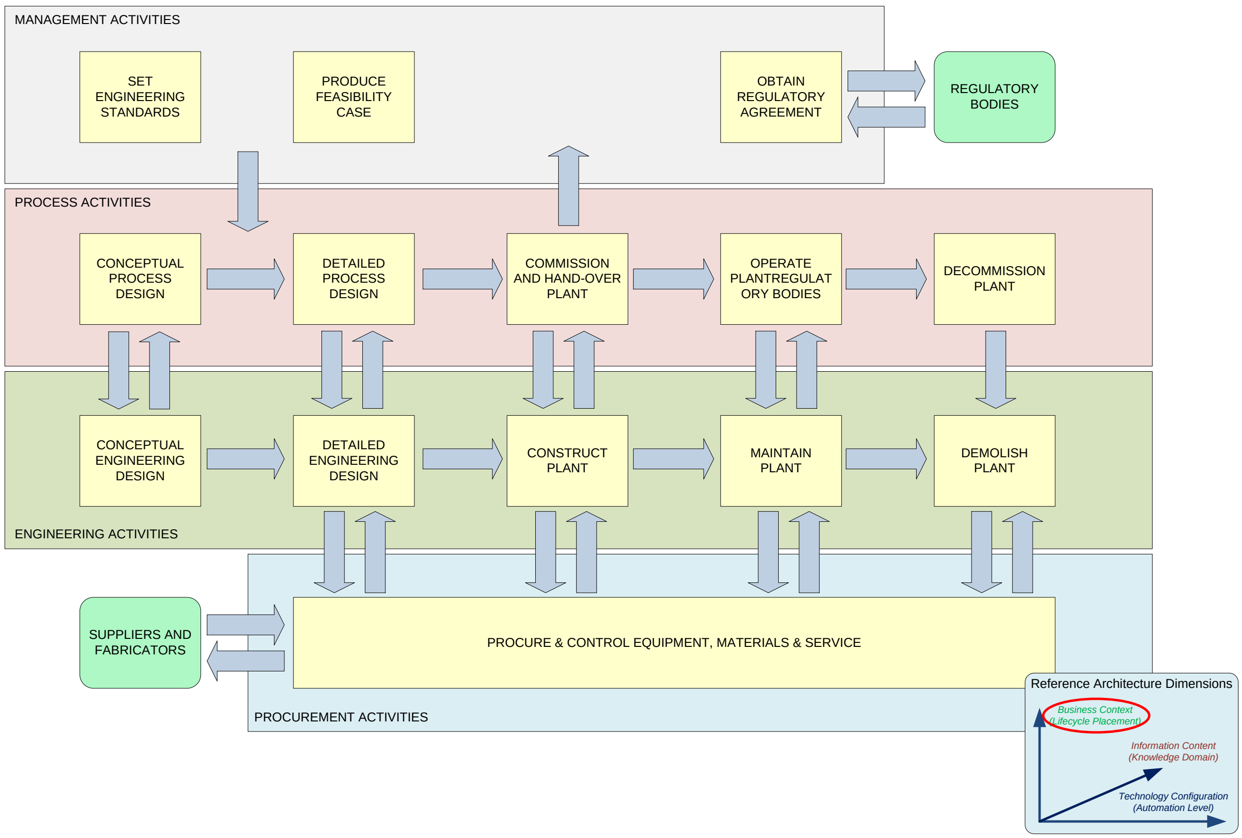

Figure 2.5: Lifecycle Activities in the Reference Architecture Framework

The figure illustrates how the lifecycle of a typical oil & gas facility (or any process plant) can be described in terms of a set of control activities, which “regulate” design, construction and operation of the process and associated plant, from conceptual design through to decommissioning and demolition. It also shows the interface between engineering and procurement and communication with suppliers and fabricators, as well as regulatory bodies.

2.3 The Information Content

Figure 2.6 shows the Information Content dimension of the architecture framework, which describes reference data knowledge representation and references based on the ISO 15926 Reference Data Library (RDL) with its set of domain specific nomenclatures and ontologies.

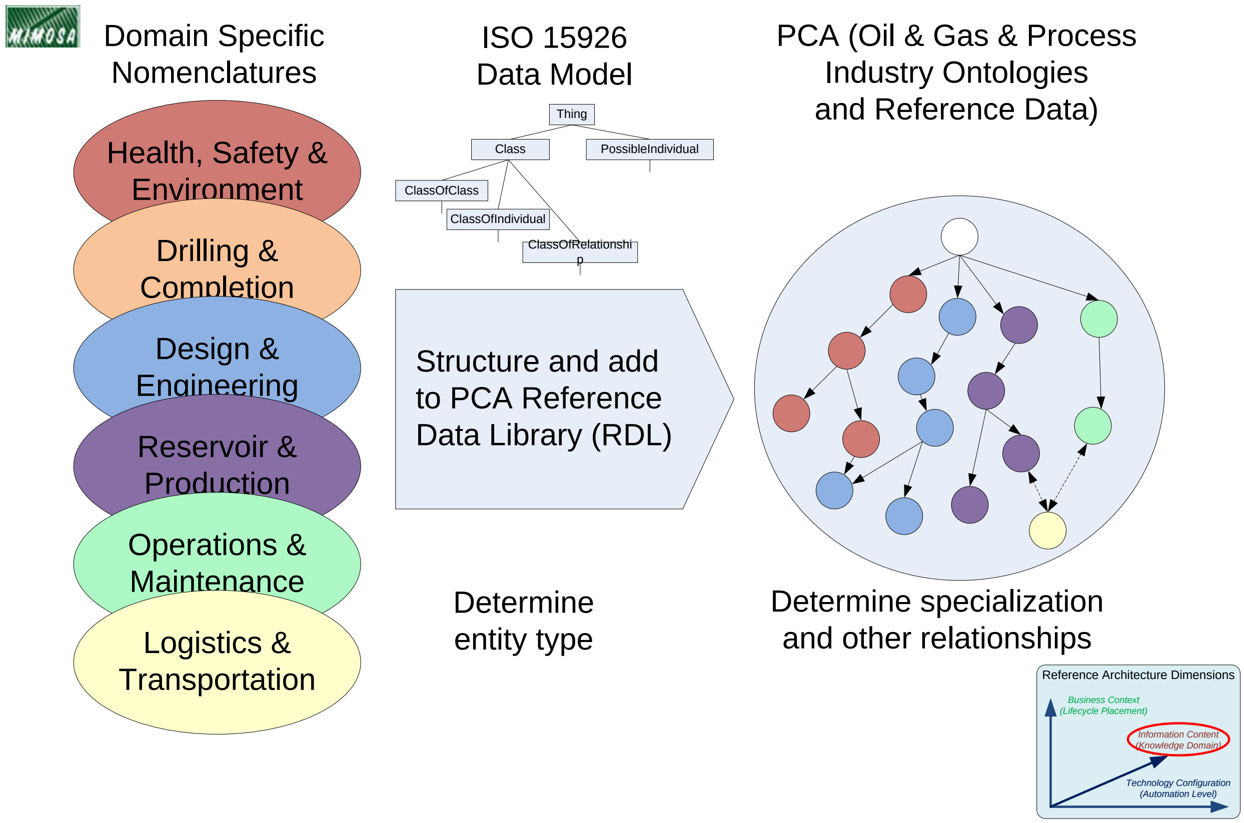

Figure 2.6: Reference Data Knowledge Representation in the Reference Architecture Framework

The figure illustrates how domain specific terms and definitions (nomenclatures), including those already defined in MIMOSA CCOM, can become instantiations of entity types in the Data Model ISO 15926 (Part 2). These "domain ontologies" contain the knowledge and structure of the areas of interest, and are typically defined using terms from the PCA RDL.

2.4 The Technology Configuration

Figure 2.7 illustrates a high level conceptual Technology Configuration perspective of how reference information represented in ISO 15926 may be exchanged between engineering and construction systems on the left hand side and the execution environment systems on the right hand side and used as input to manage operation.

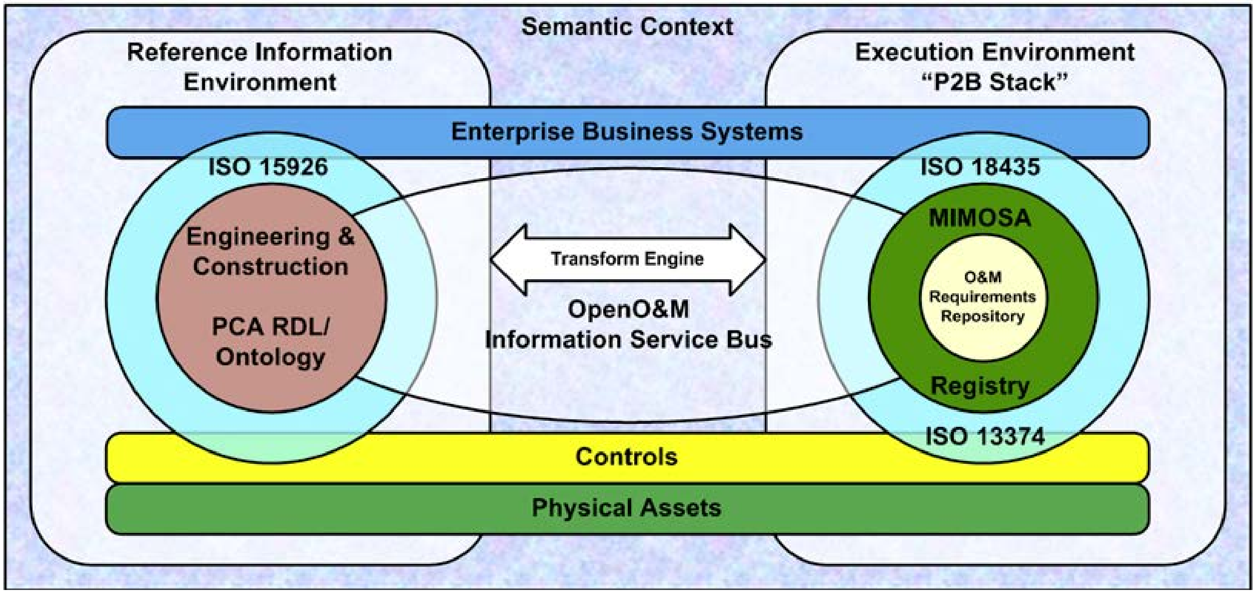

Figure 2.7: The Context for an Integrated Reference Information and Execution Environment

Figure 2.8 shows the Purdue Enterprise Reference Architecture (PERA), with Levels 0 through 4 corresponding to production systems (level 0), device control systems (level 1 and 2), manufacturing operations and execution systems (level 3), and enterprise information systems (level 4).

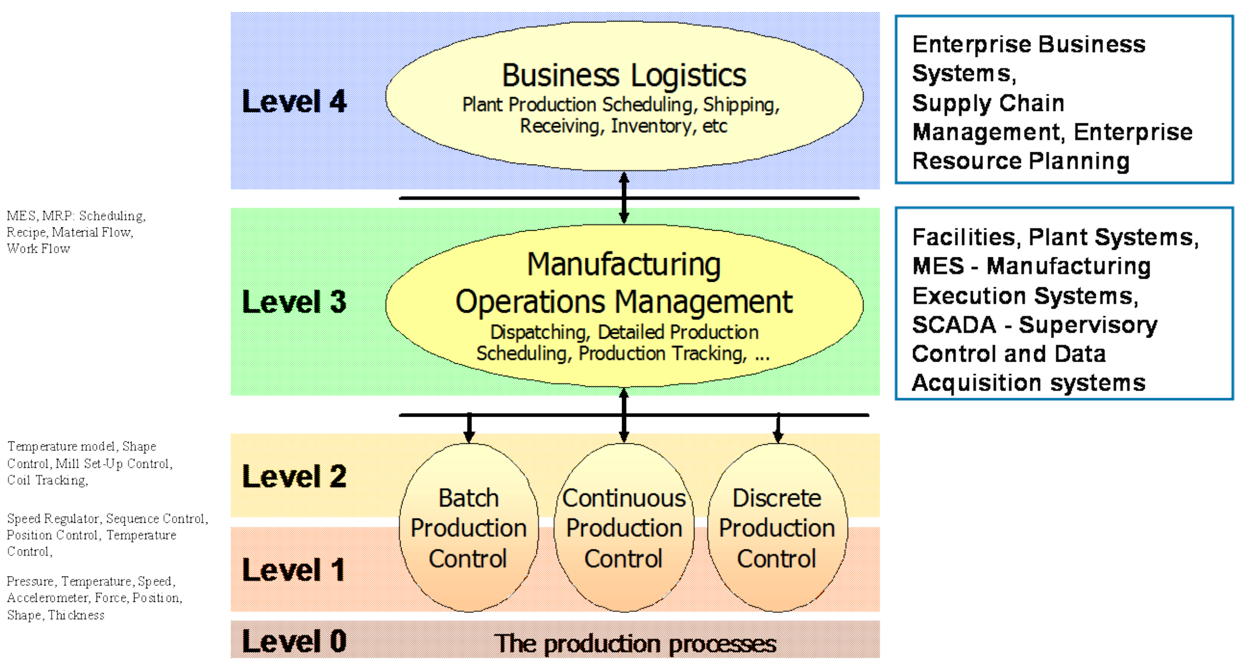

Figure 2.8: The Purdue Enterprise Reference Architecture (PERA)

Figure 2.9 shows the RAF Technology Configuration dimension, with the same levels of an integrated production, control and information system as PERA.

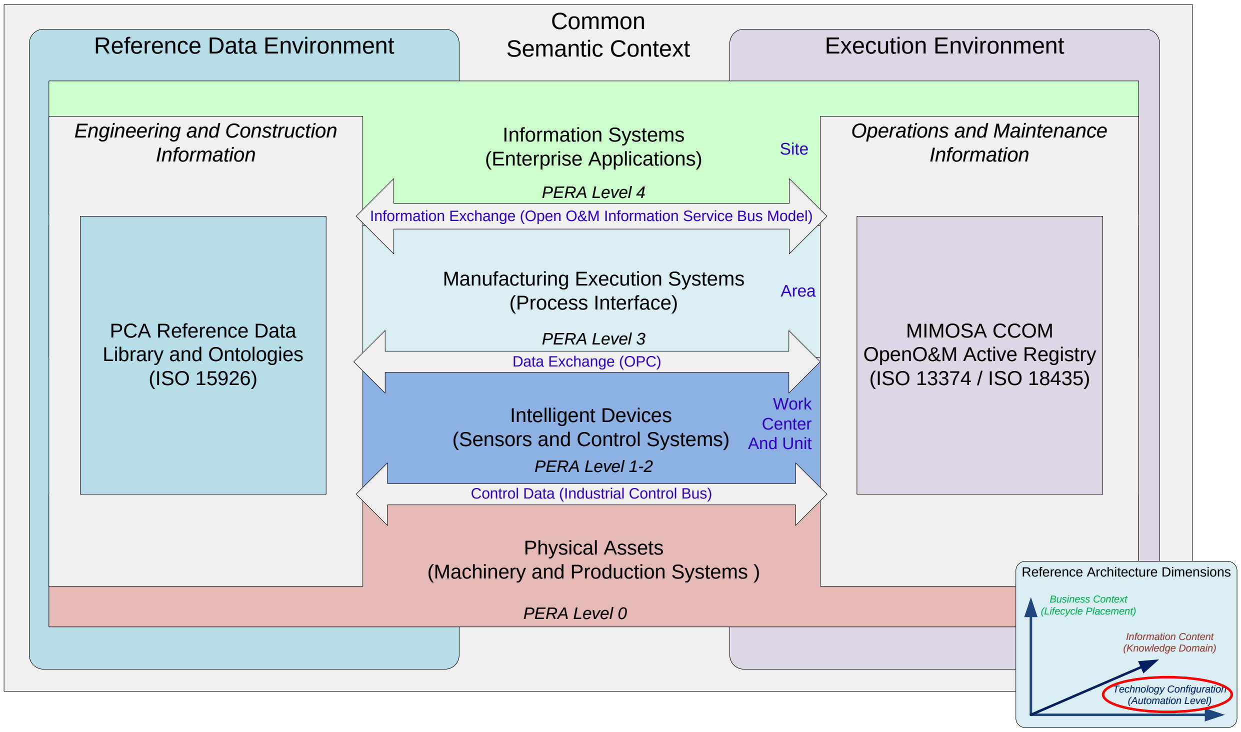

Figure 2.9: Technology Configuration in the PCA-MIMOSA Reference Architecture Framework

The figure illustrates how standards from different organizations in different industries and with different scope can be usefully interrelated and interlinked with common semantic context. Both the PCA Reference Data Library and the MIMOSA CCOM-ML O&M Active Registry (which contains the path to known objects in OpenO&M Systems of Record) are compliant with published international and industry standards.

As an example, Figure 2.10 shows the PERA model applied to manufacturing control.

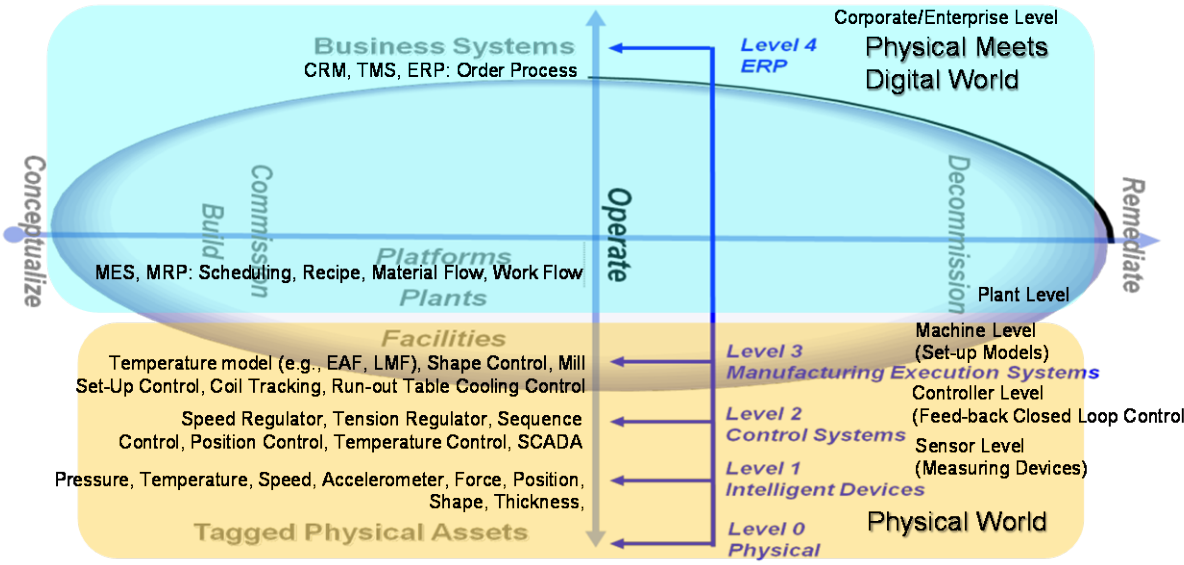

Figure 2.10: The Purdue Manufacturing Model

The figure illustrates how the entire lifecycle from conceptualization to remediation along the horizontal axis can be described in terms of a physical world of tagged physical assets, monitored and controlled by intelligent devices, control systems and execution systems, and interfaced to the digital world of Enterprise Resource Planning and other business applications. The figure also illustrates placement of the various PERA levels relative to the system configuration along the vertical axis.

3 The Reference Models

This section introduces five generalized Reference Model (RM) that describe Service Agreements, System Engineering, Software Interoperability, Semantic Ontology and Standards Usage. The various RMs can be specialized as industry and application specific RMs, which in turn can be instantiated as Architecture Models for specific applications.

3.1 The Service Agreement Reference Model

Figure 3.1 shows the Service Agreement surrounded by a set of Service Agreement Characteristics, including Stakeholder Interest (the reasons for the agreement), Business Model (of the various stakeholders), Revenue Stream and Cost Structure (of each agreement), and Communication Behavior (used to operate and deliver the agreed service).

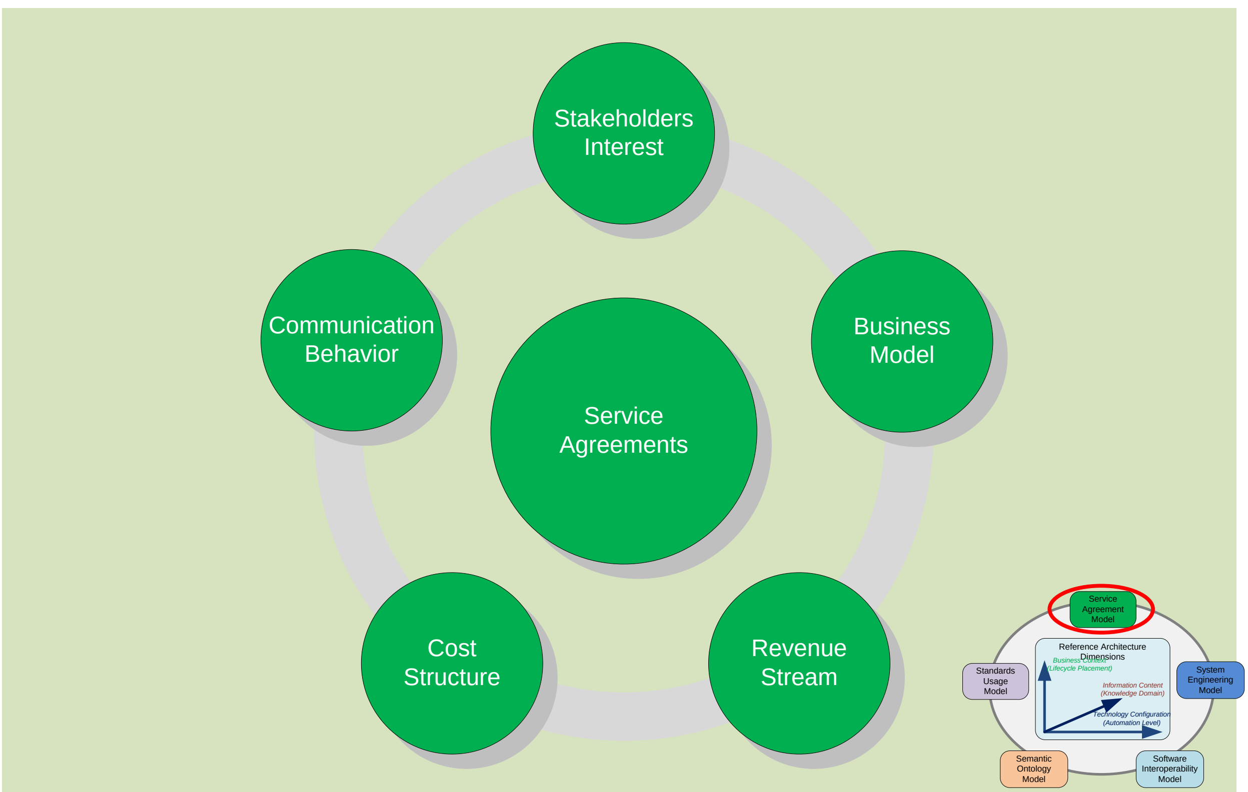

Figure 3.1: The Service Agreement Characteristics

Figure 3.2 shows the Service Agreement Reference Model for operation of offshore oil and gas fields, with the Asset Owner/Operator (Oil & Gas Company) and many other stakeholder roles.

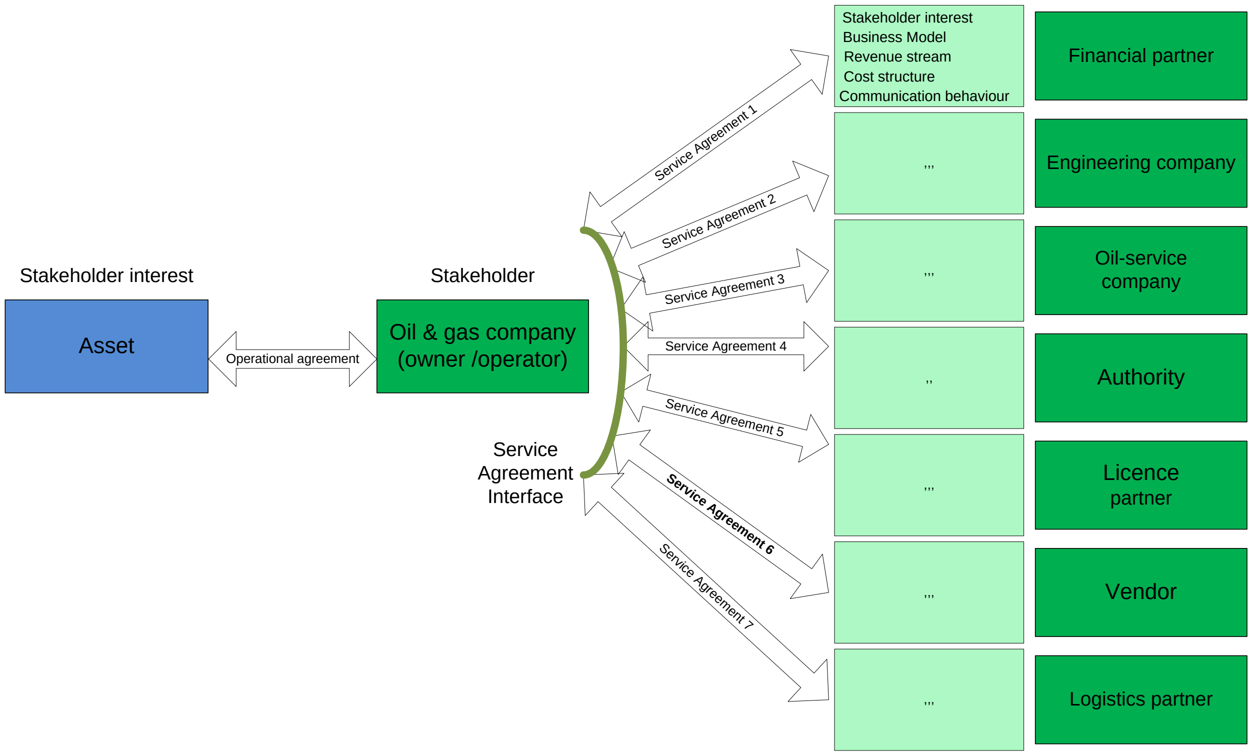

Figure 3.2: The Reference Service Agreement Model for Asset Owners

In Figure 3.2, the asset owner is the main stakeholder, with an operational agreement for the asset and a set of service agreements to other stakeholders. The Characteristics of the various service agreements are taken from figure 3.1 and (can be thought of as being) managed through a common service agreement interface to all key parties involved in exploring and exploiting the asset in question.

Below are a typical set of stakeholder roles, with examples from stakeholders currently working with PCA and MIMOSA:

- Educational institutions (e.g. Queensland University of Technology, University of Cincinnati, University of Oslo, University of South Australia)
- EPC companies (e.g. Aker Solutions, AMEC, Bechtel, WorleyParsons)
- Industry associations (e.g. Fiatech, Norwegian Oil and Gas Association)
- Owner/Operators (e.g. BP, Chevron, Dow, Southern Company, Statoil, Total, Woodside)
- Software vendors (e.g. AVEVA, Bentley, IBM, Microsoft, OSIsoft, Rockwell Automation, SAP)
- Standards representatives (e.g. MIMOSA, OpenO&M, PCA)
- Transportation companies (e.g., DHL, Bring, EuroContainer)

3.2 The System Engineering Reference Model

Figure 3.3 shows the System surrounded by a set of System Engineering Characteristics, including the conditions of the Operational Environment, the structure and technology used in the Production System Configuration, the communication and commands used in the Manufacturing Control Configuration, the applications and models used in the Information Systems Configuration, and the standards and tools used for intra- and inter- Enterprise Integration.

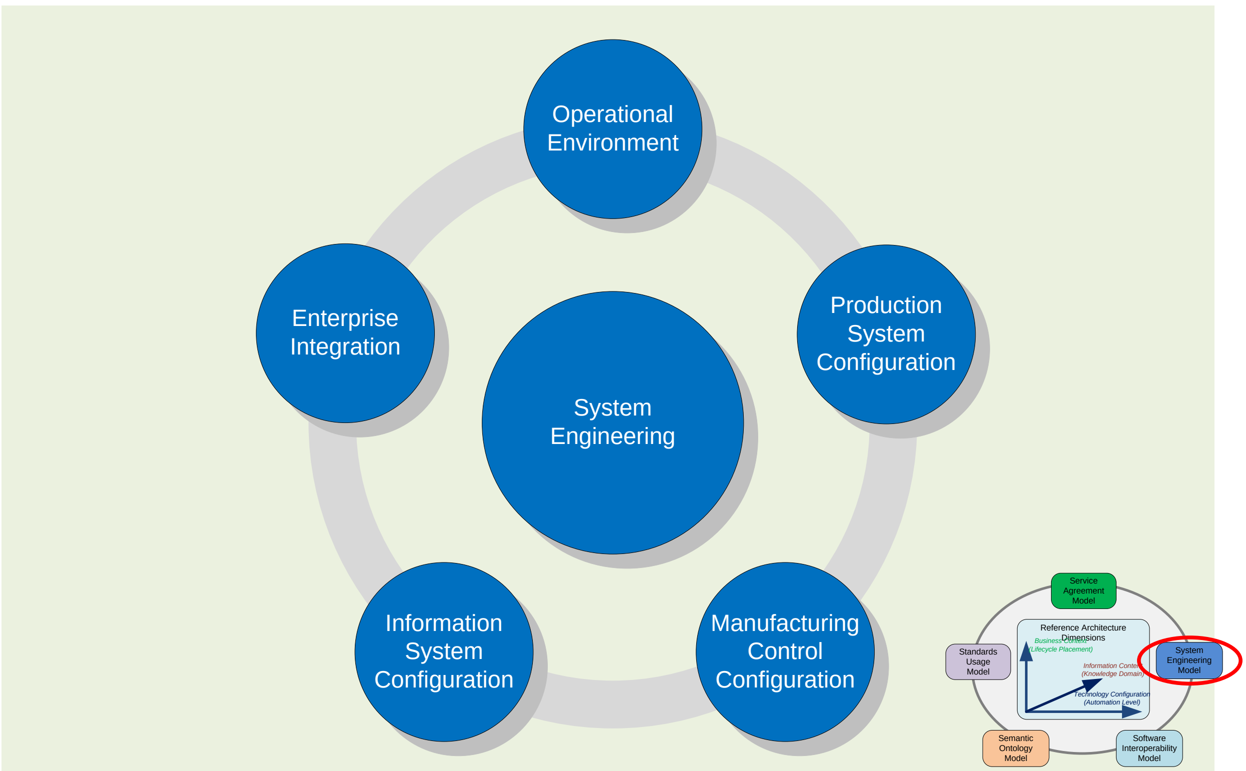

Figure 3.3: The System Engineering Characteristics

Figure 3.4 shows the System Engineering Reference Model with typical components and applications in the Operational Environment including production machinery and environmental conditions, the Production System Configuration including sensors, hardware and control devices, the Manufacturing Control Configuration management and middleware, the Information System Configuration including software tools and the Enterprise Integration layers, corresponding to PERA Levels 0 through 5.

PERA Level 0	PERA Level 1-2			PERA Level 3				PERA Level 4			PERA Level 5
Production	Control System (Sensors, Controls, Devices)			Manufacturing Operations and Control (Process Interface)				Information System (Applications)			Comm system
Physical environment	*Sensors & Controls*	*Physical Interface*	*Intelligent Devices*	*Device Interface*	*Device Management*	*Event Management*	*Data Interface*	*Data Management*	*Business Applications*		*Enterprise*
Rotation Location Temperature Forces	Sensors Regulators Actuators Antennas	Physical Control Network	SCADA Interrogators Encoders	Operations Control Network	Data Collection	Filtering and Aggregation of Data	Application Control Network	Business Process Integration	Data Service Applications	Production control and optimization	Misc. Apps
									Enterprise Business Application	Environment montoring and control	
					Device Infrastructure	Encoding and Management Rules			Back-end Application	Equipment monitoring and tracking	
									Internet Applications	Interprise communic. and coordination	

Figure 3.4: The System Engineering Reference Model

In Figure 3.4, the white control network indicators may be realized by a multitude of communication standards and a wide range of communication protocols on wireless and wired networks. The PERA levels at the top of the figure indicate the extent and coverage of each layer.

3.3 The Software Interoperability Reference Model

Figure 3.5 shows the Software surrounded by a set of Software Interoperability Characteristics including the chosen Technology Platform, Architectural Style, Programming Paradigm, Integration Mechanism and Data Storage. This describes the Characteristics of patterns and paradigms chosen in order to realize the technology configuration and content as an integrated and executable system infrastructure, as well as software characteristics such as reliability, availability, maintainability, supportability, extensibility and quality.

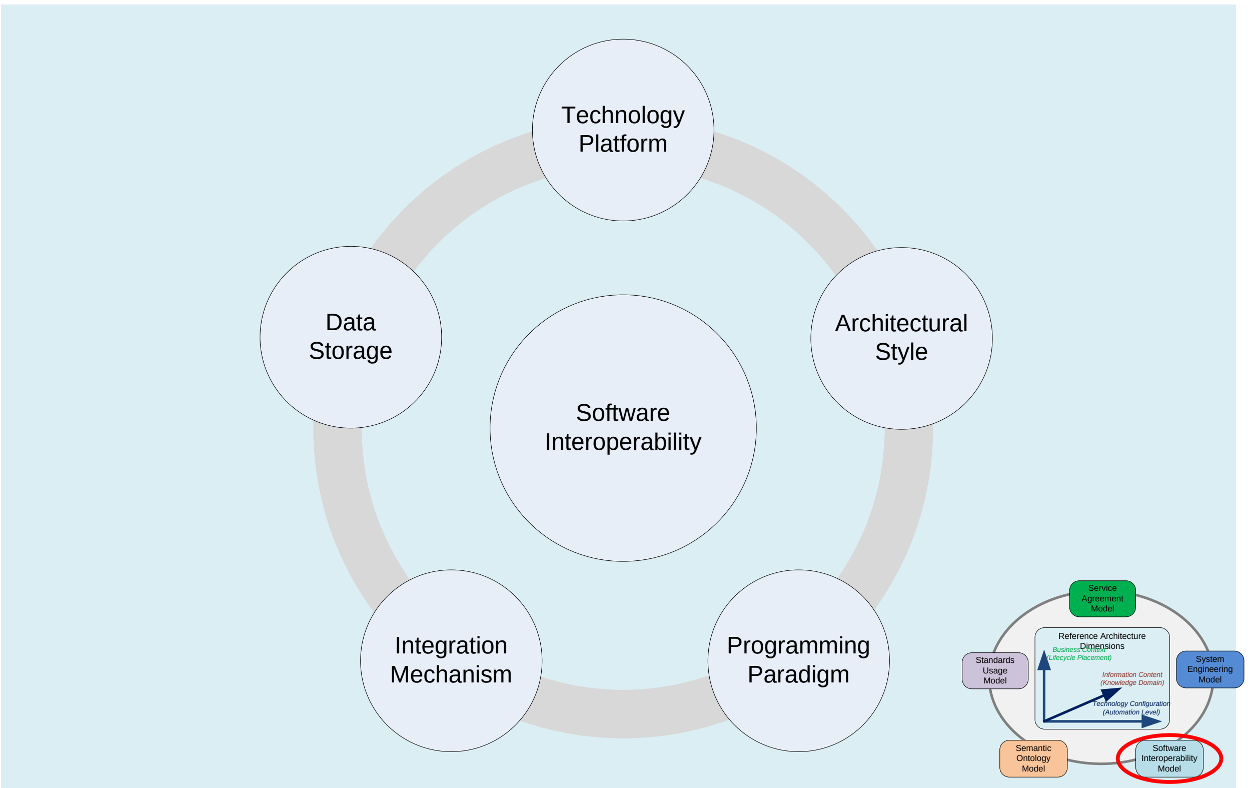

Figure 3.5: The Software Interoperability Characteristics

Figure 3.6 shows the Software Interoperability Reference Model using a Service Bus platform which implements an event-driven architecture, with loose coupling that can handle applications built using a variety of programming paradigms. Interoperability is based on message exchange with standard syntax and semantics, and with reference data hosted in a Reference Data Library.

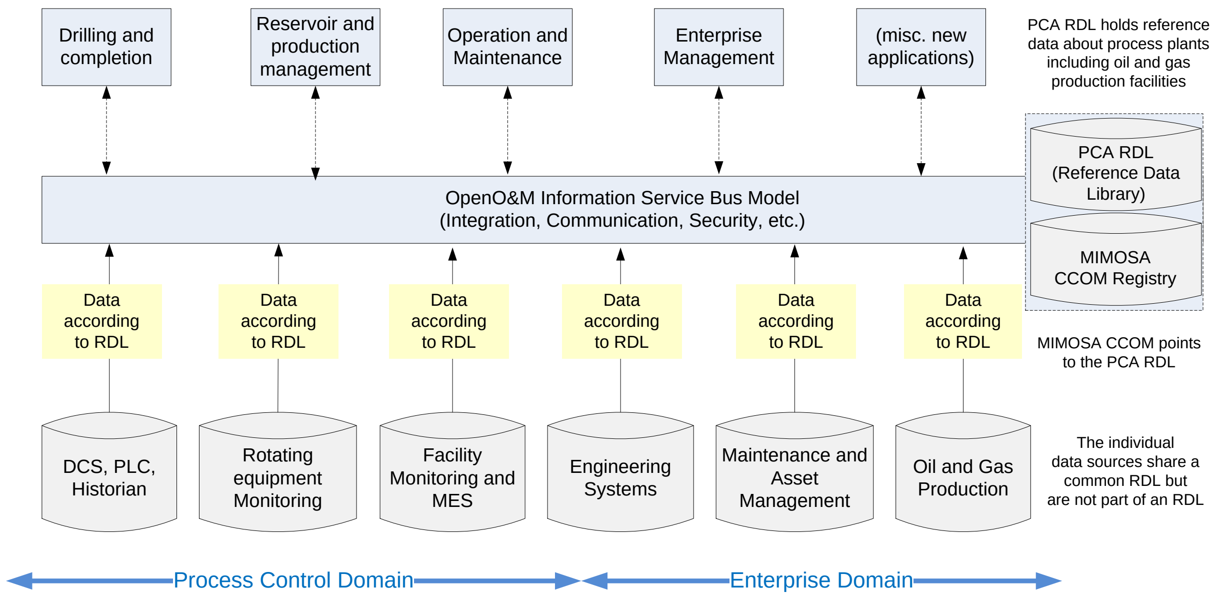

Figure 3.6: The Software Interoperability Reference Model

In Figure 3.6, all applications and data sources are connected to a common PCA-MIMOSA information service bus which can be implemented using any enterprise service bus which conforms to the OpenO&M Information Service Bus Model (ISBM). Because information exchanges across the service bus uses syntax and semantics defined by the PCA Reference Data Library (RDL) based on ISO 15926 and MIMOSA's CCOM Registry and OGI Pilot Business Object Documents, the applications can access and interpret data from a variety of data sources, with information from sensors, control devices and enterprise systems at all PERA levels. The applications also use the service bus to communicate with each other, again using shared syntax and semantics.

Figure 3.7 shows the OpenO&M Information Service Bus Model (ISBM) which provides a standard interface to any Enterprise Service Bus (ESB) or to any other message or file exchange system that offers guaranteed message and storage or caching of exchanged messages.

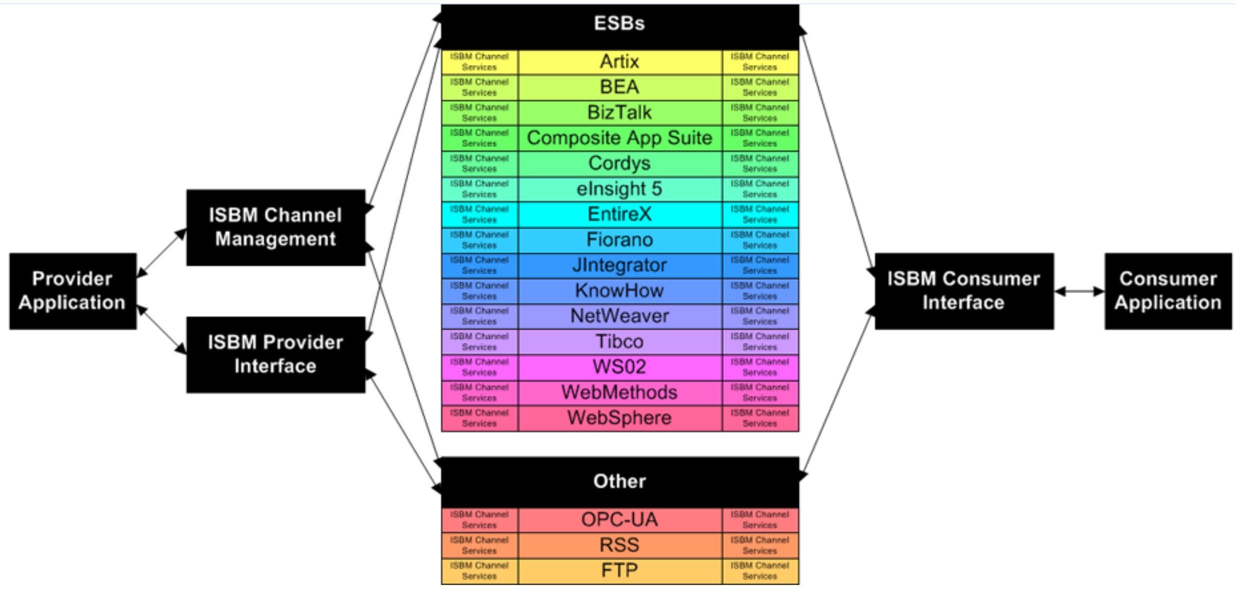

Figure 3.7: The OpenO&M ISBM for connectivity within Layer 3

An OpenO&M-compliant ISBM system shall conform to the OpenO&M Information Service Bus Model specification, including support for the SOAP web services defined in the associated WSDL. The bus is responsible to guarantee the delivery of messages to active subscribers and report any undeliverable messages to non-active subscribers.

Each ISBM-compliant system shall also define the level of support for security, reliability, guaranteed delivery, quality of service, and transformation capability. Message topics should follow the definitions found in the OGI Use Case Specifications. Message content should comply with the published OpenO&M standard XML schema, such as MIMOSA CCOM-ML.

3.4 The Semantic Ontology Reference Model

Figure 3.8 shows the Semantic Ontology surrounded by a set of Characteristics including the chosen Purpose, Scope, Modeling Paradigm, Modeling Constructs, and Reference Classes.

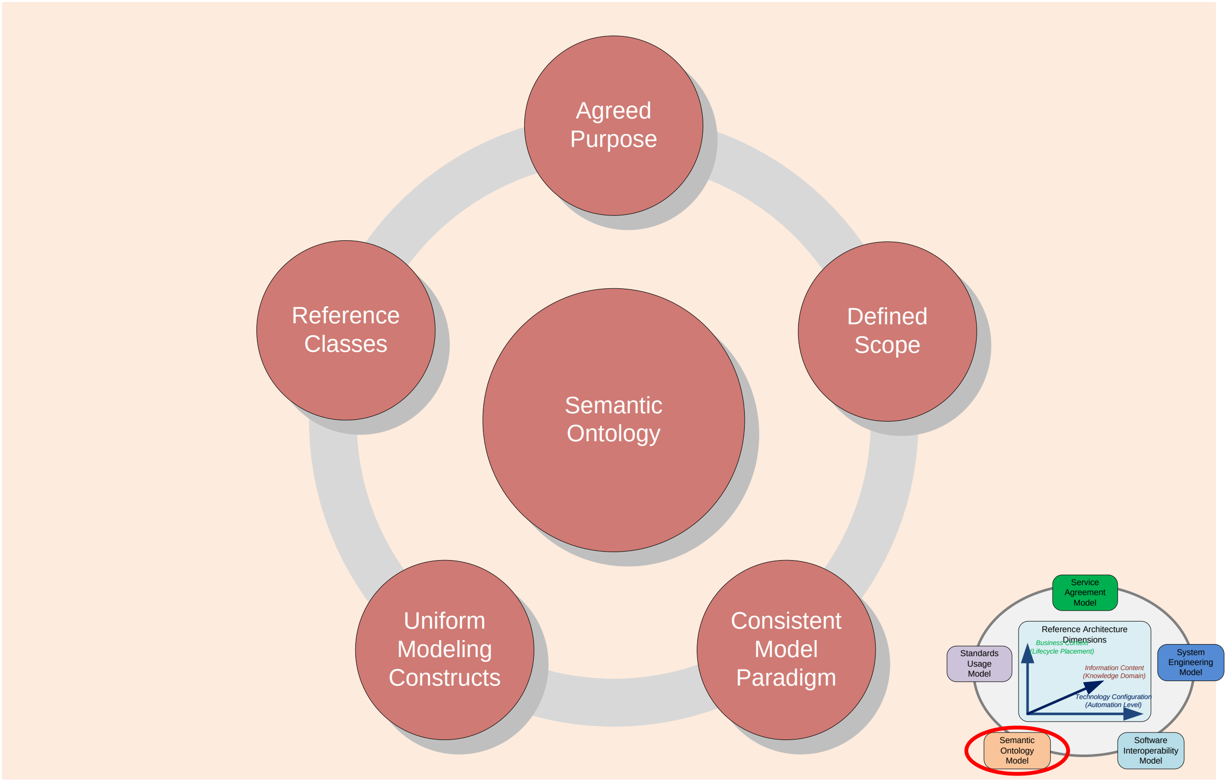

Figure 3.8: The Semantic Ontology Characteristics

Figure 3.9 shows the Semantic Ontology Reference Model based on ISO 15926 for describing for process plants including oil and gas production facilities with a consistent upper level data model and an extensive and ordered set of reference data in a system of federated data libraries.

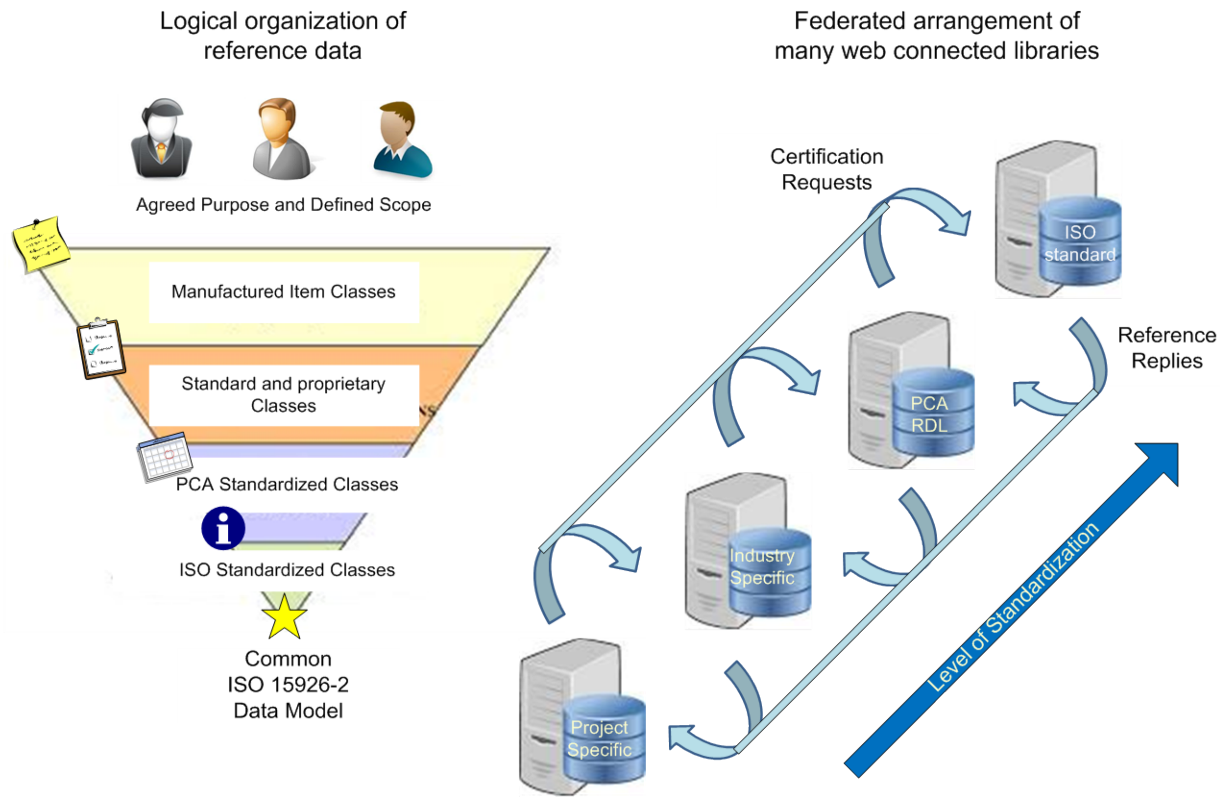

Figure 3.9: The Semantic Ontology Reference Model

In Figure 3.9, classes in the various RDLs, which may be arbitrarily placed all over the Internet, are typically connected by specialization relationships such that class A in a private or community data store is the subclass of class B in a Global Reference data library – which may in turn be a specialized subclass of a standard class in the PCA or ISO "official reference" RDL.

3.5 The Standards Usage Reference Model

Figure 3.10 shows the Standards Usage surrounded by a set of Characteristics including the chosen standards for Semantic Technology, Reference Data, Metadata, Data Quality and Data Security.

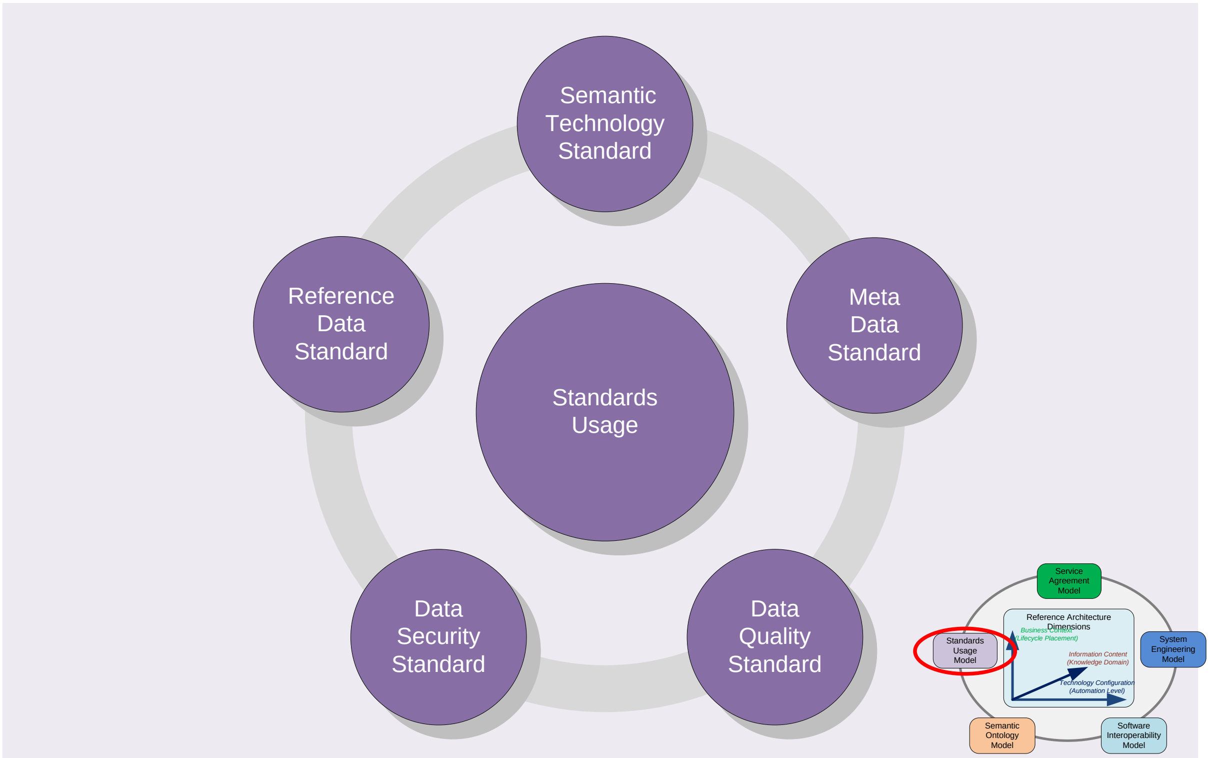

Figure 3.10: The Standards Usage Characteristics

Figure 3.11 shows the technology stack for the Reference Data Environment (see figure 2.7) based on W3C semantic technology standards, with layers for addressing (URI), encoding (XML), data interchange (RDF), data classes (RDFS), data queries (SPARQL), rules (SPIN), ontologies (OWL), inferences (First Order Logic), etc.

The structure of this technology stack is a modification of the W3C Semantic Technology Stack, where ISO 15926 Part 2 (Data Model) implements Model consistency, and ISO 15926 Part 4 (Reference Data Library) is used to provide classes and relationships that support trusted contents. The ongoing and forthcoming EPIM Information Hubs illustrate typical user applications. See Appendix D and Appendix E for classification of two such information hubs.

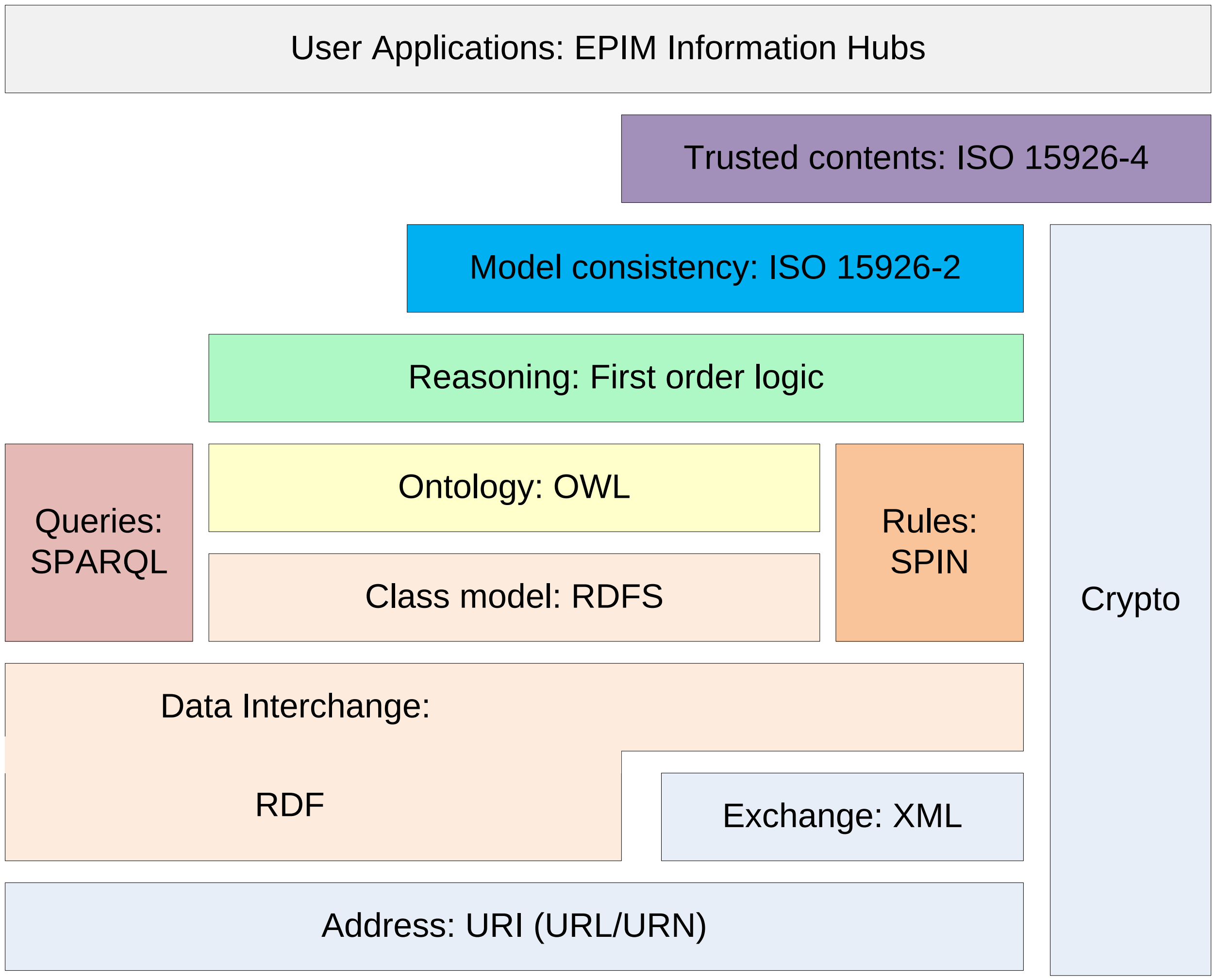

Figure 3.11: The PCA-MIMOSA Reference Information Technology Stack

Figure 3.12 shows the technology stack for the Execution Environment (see Figure 2.7) based on the ISO 13374 and ISO 18435 standards for software specification, integration and communication at the production and control systems levels.

The structure of this technology stack includes transport compliant with OPC Foundation Standards, web services using SOAP and WSDL, service buses compliant with the OpenO&M ISBM, data encoding and interchange using XML/XSD, message architecture using OAGIS Business Object Documents, and data modeling using UML.

The ongoing MIMOSA-PCA OGI Industry Pilot illustrates a typical user application. See Appendix A for classification. See Appendix B and Appendix C for two other application examples involving components from the technology stack for the Execution Environment.

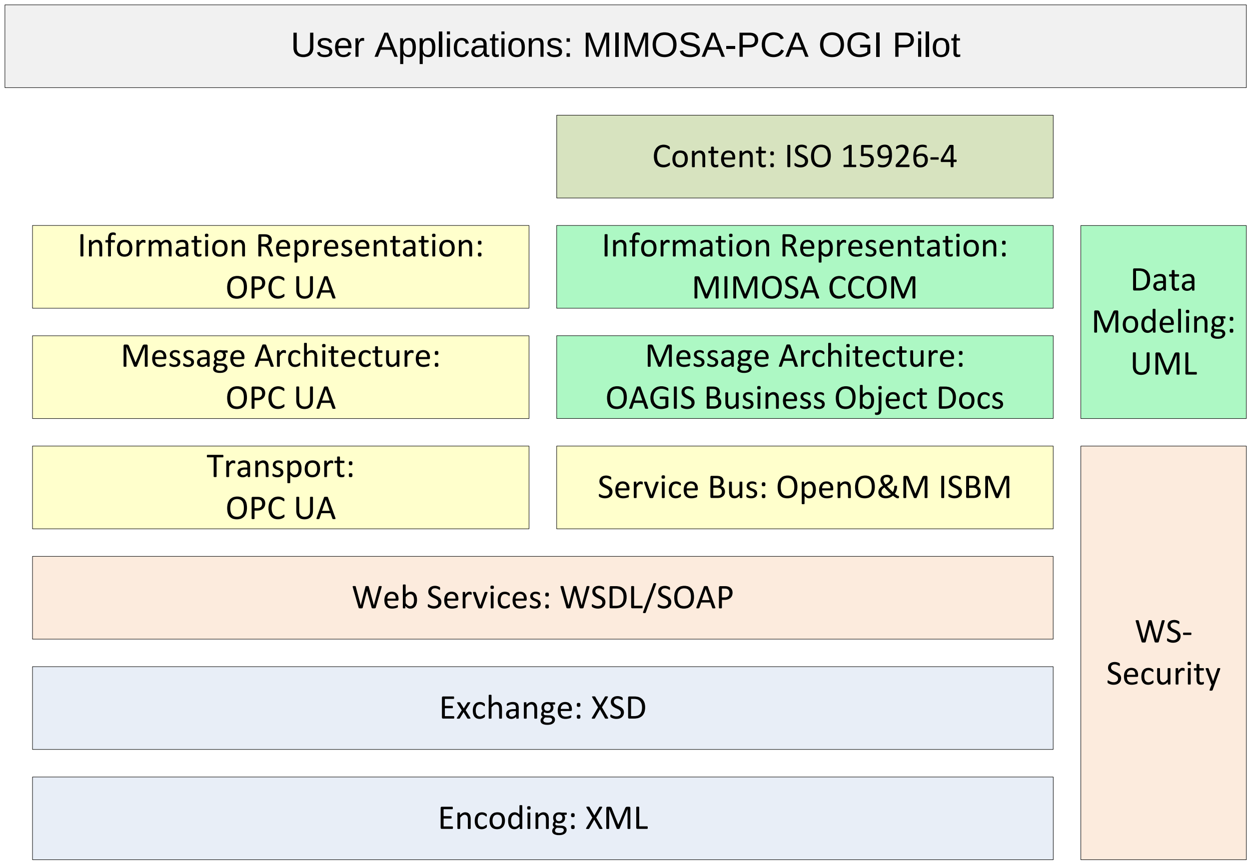

Figure 3.12: The MIMOSA-PCA Execution Environment Technology Stack

ISO 13374-1 establishes general guidelines for software specifications related to data processing, communication, and presentation of machine condition monitoring and diagnostic information

ISO 18435-1 defines an integration modeling method and its use to integrate diagnostics, capability assessment, prognostics and maintenance applications with production and control applications.

See also Appendix F for an overview of relevant standards.

4 The Reference Architecture Instantiations

A set of instantiated Architectures are presented in Appendix A through Appendix E illustrating:

- Appendix A: Handover in OGI Pilot (PCA & MIMOSA)
- Appendix B: Collaborative Telemaintenance (MIMOSA)
- Appendix C: Integrated Engineering Asset Mgt. (MIMOSA)
- Appendix D: Production Optimization (PCA)
- Appendix E: Logistics Tracking (PCA)

For each of these Applications, the RAF has been used to "classify" their Architecture by defining Configuration, Content and Context (using the RAD) and describing Stakeholders, System, Software, Semantics and Standards (using the RMs). As can be seen by comparing these classifications, the examples comply with the reference architecture to varying degrees. The project that most closely complies with the full scope of the architecture is "Handover in OGI Pilot", while the other examples include parts of the reference architecture and relevant standards. However, all of the examples display architectural patterns and characteristics, and are useful to further understand the complete reference architecture framework.

Table 4.1 to Table 4.6 summarize the classification of these Application Architectures in terms of the Reference Architecture Dimensions and Reference Model Characteristics. Further details can be found in the various appendices.

Architecture Dimension	**Technology Configuration**	**Information Content**	**Business Context**
Handover in OGI Pilot	Web services and endpoint at PERA Level 4	System Engineering Registry	Capital projects
Collaborative Telemaintenance	Web services and endpoint at PERA Level 4	Condition Based Maintenance information	Maintenance
Integrated Engineering Asset Mgt.	XML data conversion at PERA Level 4	Condition, Maintenance and Reliability events	Maintenance
Production Optimization	Standard XML reports at PERA Level 4	Reporting Drilling activity and Production volumes	Field exploration and Operation
Logistics Tracking	Web services and endpoint at PERA Level 4	Tracking specified logistics events	All parts of Lifecycle

Table 4.1: Summary of Architecture Framework Dimensions for the Application Architectures

Service Agreement Model	**Stakeholder interest**	**Business Models**	**Revenue Streams**	**Cost Structures**	**Communication Behavior**
Handover in OGI Pilot	Reduction in time and errors in capital project handovers	Reduce cost with increased usable information	Makes more capital available for additional capital projects	Cost shared by EPC / operators	Bi-directional FEED information flows to O&M systems during engineering, procurement, and construction
Collaborative Telemaintenance	Information for maintenance and operational decision support	Reduce risk and costs	No new streams	Cost paid by operators	Input to maintenance and decision support systems
Integrated Engineering Asset Mgt.	Information for maintenance and operational decision support	Reduce risk and costs	No new streams	Cost paid by operators	Input to maintenance and decision support systems
Production Optimization	Regulatory compliance	Required reporting from authorities	Reporting of production share to license partners	Cost paid by operators	Input from operators, output to authorities
Logistics Tracking	Information for logistics optimization	Save time and cost	No new streams	Shared development cost	Receive input from RFID tags

Table 4.2: Summary of Service Agreement Characteristics for the Application Architectures

Systems Engineering Model	**Operational Environment**	**Production System Configuration**	**Manufacturing Control Configuration**	**Information System Configuration**	**Enterprise Integration**
Handover in OGI Pilot	Refining	EPC information	EPC information	XML messages, multiple persistence technologies	OpenO&M Information Service Bus
Collaborative Telemaintenance	O&M	Equipment CBM and health information	Equipment CBM measurement and events	XML messages and Web services	MIMOSA OSA-EAI
Integrated Engineering Asset Mgt.	Multiple industries	Equipment CBM and health information	Equipment CBM and health information	XML messages, RDBMS persistence	Web services and file exchange
Production Optimization	Offshore drilling and production	Measurements in exploration and production wells	Equipment control and communication	XML messages and semantic triple-store	SOIL (Secure Oil Information Link)
Logistics Tracking	RFIDs on Cargo Carrying Units	RFID Tags	Readers, Devices	Web services and semantic triple-store	SOIL (Secure Oil Information Link)

Table 4.3: Summary of System Engineering Characteristics for the Application Architectures

Software Integration Model	**Technology Platform**	**Architectural Style**	**Programming Paradigm**	**Integration Mechanism**	**Data Storage**
Handover in OGI Pilot	Multiple technologies used by suppliers	Web service bus	XSD, OWL	Web services	Multiple persistence technologies used by suppliers
Collaborative Telemaintenance	SOAP	Web services receiving and delivering data	XML/XSD	SOAP Web services	Multiple persistence technologies used by suppliers
Integrated Engineering Asset Mgt.	Microsoft .NET WCF, WPF, SQL Server	Hub and spoke with 3-tier application architecture	XML/XSD	Web services and file exchange	SQL RDBMS
Production Optimization	TopBraid Suite and triple-store	Input data used in standard XML reports	XML/XSD	Web services	RDF-triples
Logistics Tracking	TopBraid Suite and Oracle TDB	Web services receiving and delivering data	SPARQL queries, SPIN rules	Restful Web Services	SQL database with RDF-triples front-end

Table 4.4: Summary of Software Integration Characteristics for the Application Architectures

Semantic Ontology Model	**Agreed Purpose**	**Defined Scope**	**Consistent Modeling Paradigm**	**Uniform Modeling Constructs**	**Reference Classes**
Handover in OGI Pilot	Provision O&M systems	System engineering registry	Agreed upon XML Schema and OWL Templates	ISO 15926 Parts 2 and 4, MIMOSA CCOM	PCA RDL, MIMOSA CCOM Reference Data
Collaborative Telemaintenance	Deliver CBM information	Monitored equipment health events	Agreed upon XML Schema and Web services	MIMOSA CRIS	MIMOSA CRIS Reference Data
Integrated Engineering Asset Mgt.	Deliver reports	All maintenance, reliability and condition events	Agreed upon XML Schema using standard terms	MIMOSA CRIS	MIMOSA CRIS Reference Data
Production Optimization	Deliver reports with mandated information in standard format	Daily Drilling, Daily and monthly Production	Agreed XML Schema using standard terms	ISO 15925 Parts 2 and 4	WITSML Reference Data in PCA RDL
Logistics Tracking	Standardize tracking of CCUs	Store all specified events	Unified event model of logistics life-cycle	ISO 15925 Parts 2 and 4	CCU Reference Data in PCA RDL

Table 4.5: Summary of Semantic Ontology Characteristics for the Application Architectures

<u>Standards Usage Model</u>	**Semantic Technology Standard**	**Metadata Standard**	**Data Quality Standard**	**Data Security Standard**	**Reference Data Standards**
Handover in OGI Pilot	XSD, OWL, WSDL/SOAP	Guidance from ISO 15926 and MIMOSA CCOM	Guidance from ISO 15926 and MIMOSA CCOM	WS-Security through OpenO&M ISBM	ISO 15926, MIMOSA CCOM
Collaborative Telemaintenance	XSD	MIMOSA CCOM	MIMOSA CCOM	SSL/TLS	MIMOSA CRIS
Integrated Engineering Asset Mgt.	SQL, WSDL/SOAP, XML/XSD	MIMOSA CRIS	Guidance from MIMOSA CRIS	SSL/TLS	MIMOSA CRIS
Production Optimization	SPARQL, SPIN, RDFS/OWL, RDF, XML./XSD	Guidance from ISO 15926 and W3C	Guidance from ISO 15926 and W3C	Provided by SOIL	ISO 15926, WITSML
Logistics Tracking	SPARQL, SPIN, RDFS/OWL, RDF, XML./XSD	Guidance from ISO 15926 Part 6	Guidance from ISO 15926	Provided by SOIL	ISO 15926, GS1/GSN

Table 4.6: Summary of Standards Usage Characteristics for the Application Architectures

5 Conclusions and Further Work

This document has introduced the PCA-MIMOSA Architectural Reference Framework (RAF), Reference Architecture Dimensions (RAD) and Reference Models (RM), and illustrated how they may be applied to define and describe (classify) a set of application specific architectures from a wide range of industrial settings and applications.

The current RAF should be extended with a Reference Architecture Methodology (RAM) to become a complete Generalized Enterprise Reference Architecture Methodology and Framework (GERAM) as illustrated in Figure 5.1.

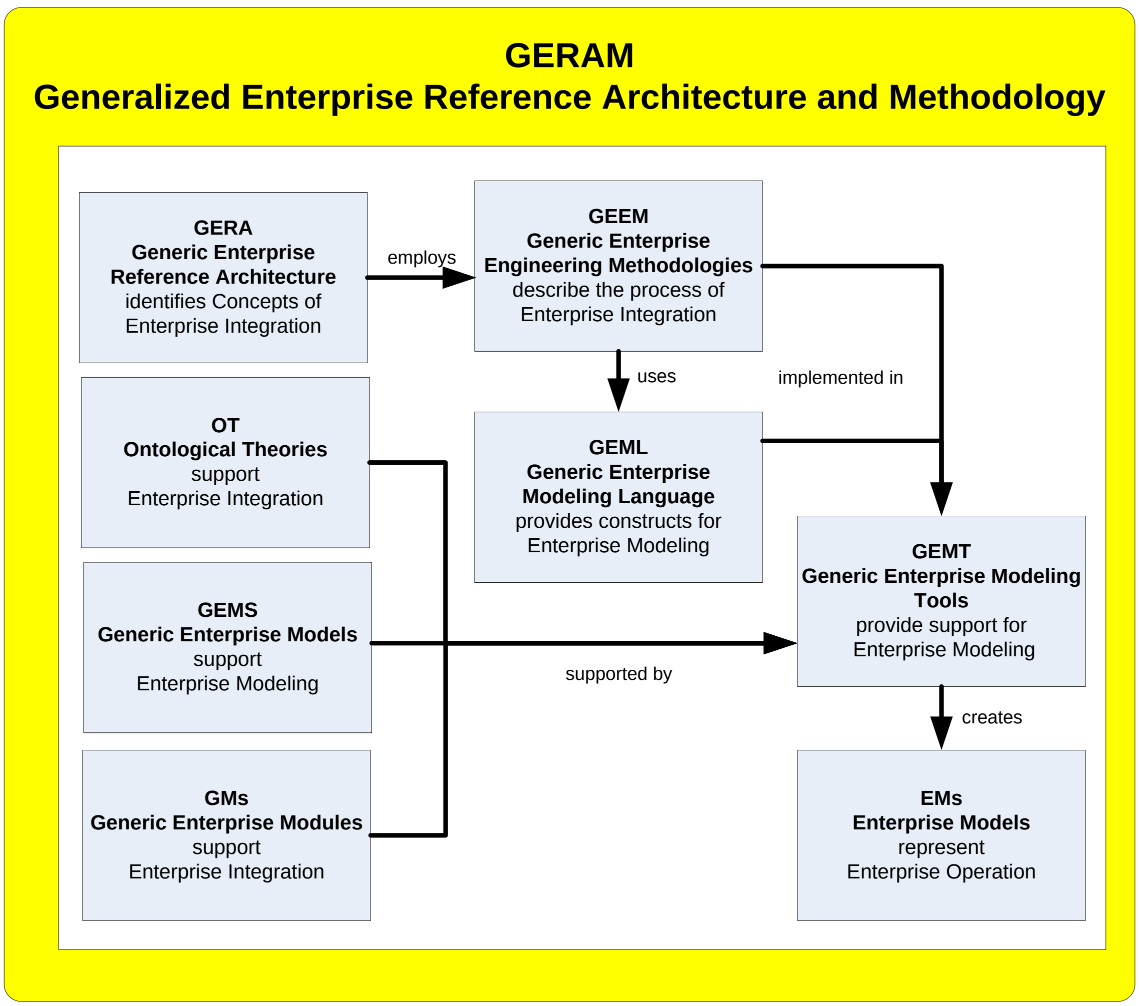

Figure 5.1: A Generalized Enterprise Reference Architecture and Methodology

From Figure 5.1, we recognize the use of Generic Enterprise Reference Architectures (GERA) through RAF, Ontological Theories (OT) through ISO 15926 Part 2, Generic Enterprise Models and Modules (GEMS and GMs) through RMs and Reference Classes, and the use of Generic Enterprise Modeling Language (GEML) through OWL/RDF.

What is missing in particular is a Generic Enterprise Engineering Methodology (GEEM) to define and describe how enterprise integration can and must accompany introduction of IT Architectures in order to develop Enterprise Models that fully describe enterprise operations and can be used in execution of those operations.

Alternative methods and tools can be found in Enterprise Architecture Frameworks such as the Federal Enterprise Architecture Framework (FEAF) – to structure reference models and The Open Group Architecture Framework (TOGAF) – to structure architecture methodology.

Appendix A Handover in OGI Pilot

Figure A.1 illustrate the software applications and application architecture involved in handover of information from EPC vendors to Operations and Maintenance. In order to view this Application Architecture through the lens of the PCA-MIMOSA Reference Architecture Framework a summary of relevant information for the Reference Architecture Dimensions (RAD) and Reference Models (RM) is given below the figures.

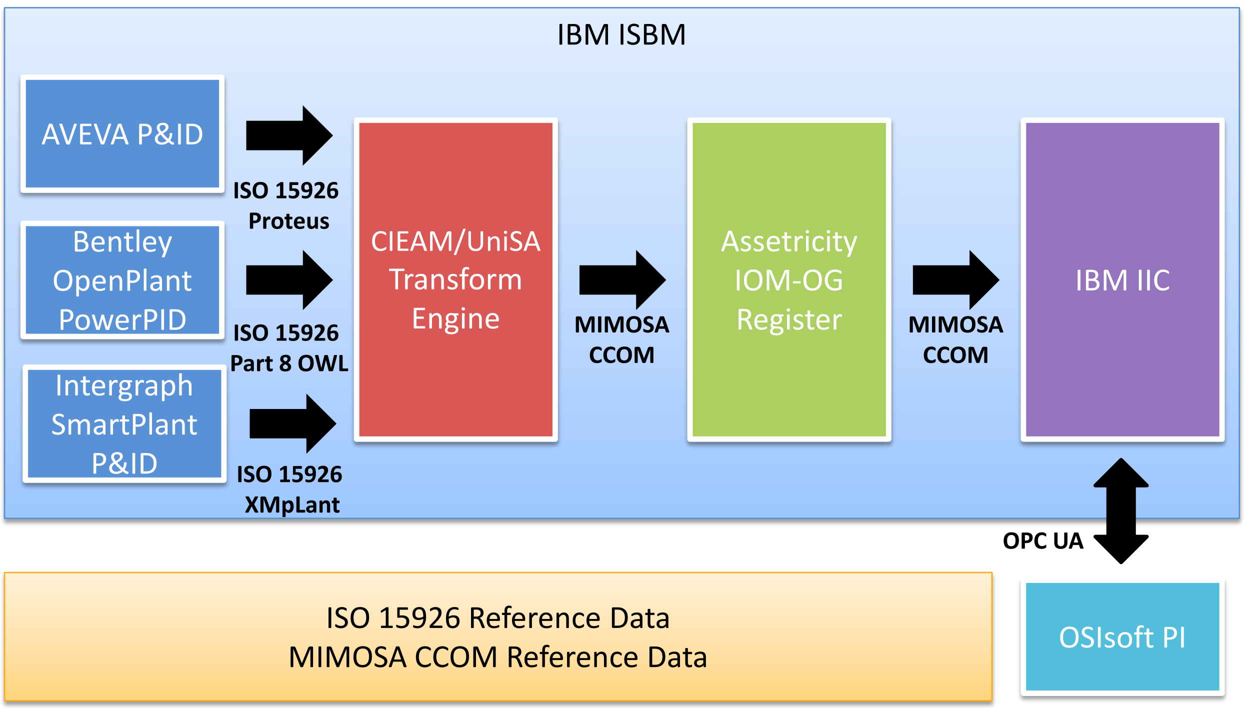

Figure A.1: Applications in information handover from EPC vendors to O&M Systems

Classifying the Application Architecture used for the OGI Pilot Handover application according to the PCA-MIMOSA RAF:

Technology Configuration Dimension

- Control and Monitoring Systems at PERA Levels 1 and 2
- Manufacturing Operations and Management at PERA Level 3
- Information System Applications at PERA Level 4

Information Content Dimension

- Oil and Gas interoperability (OG) Downstream Pilot Demo: Information hand-over from EPC Vendor IT environment to Owner/Operator IT environment

- Developing and Managing Engineering Data Sets
- Providing standard engineering artifacts used for EPC process

Business Context Dimension

- AVEVA P&ID, Bentley Open Plant, XML and OWL transforms,
- IBM ISBM provides connectivity environment, ESB, IBM IIC, OSIsoft PI/AF

Service Agreement Model

- EPC Vendor
- Owner/Operator

System Engineering Model

- PERA levels 3 and 4

Software Interoperability Model

- Bentley OpenPlant produces OWL/ecXML; AVEVA P&ID produces Proteus; and Intergraph produces XMpLant
- All formats are transformed from ISO 15926 to MIMOSA CCOM-ML by UniSA Transform Engine
- Data is received and staged in the IOM-OG Register and subsequently sent to IBM IIC
- OPC UA Tag Register delivered from IBM IIC to OSIsoft PI/AF Data Historian

Semantic Ontology Model

- Relevant classes and relationships from PCA RDL and other federated data sources
- Relevant terms and semantic meta model definitions from MIMOSA CCOM

Standards Usage Model

- ISO 15926, PCA RDL classes,
- MIMOSA CCOM, OPC UA
- OWL/RDF, XML Schema, OMG MOF, OCL, QVT

Appendix B Telemaintenance Demo Project

This Army CECOM-funded project built upon the established MIMOSA intellectually property, some of which had been previously funded by the Office of Naval Research (OSA-CBM). The project created a multi-tier Collaborative Maintenance environment is in keeping with the strategic direction of maintenance and supply chains throughout the Department of Defense.

Already having selected MIMOSA's OSA-CBM technology for integration of condition-based maintenance, the CTM project team searched for various open EAI architectures and only found one specification which meets its requirements -- the Open System Architecture for Enterprise Application Integration (OSA-EAI) specification developed by the Machinery Information Management Open Systems Alliance (MIMOSA).

Figure B.1 and Figure B.2 illustrate the applications and application architecture utilized in the project. In order to view this Application Architecture through the lens of the PCA-MIMOSA Reference Architecture Framework a summary of relevant information for the Reference Architecture Dimensions (RAD) and Reference Models (RM) is given below the figures.

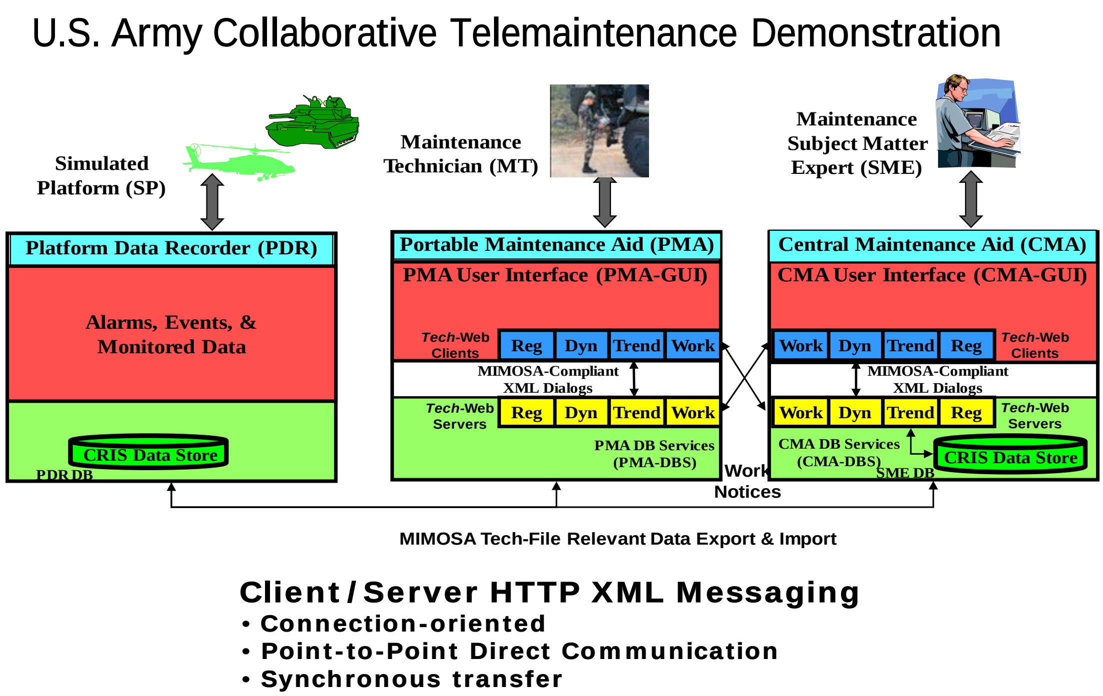

Figure B.1: System Application Architecture

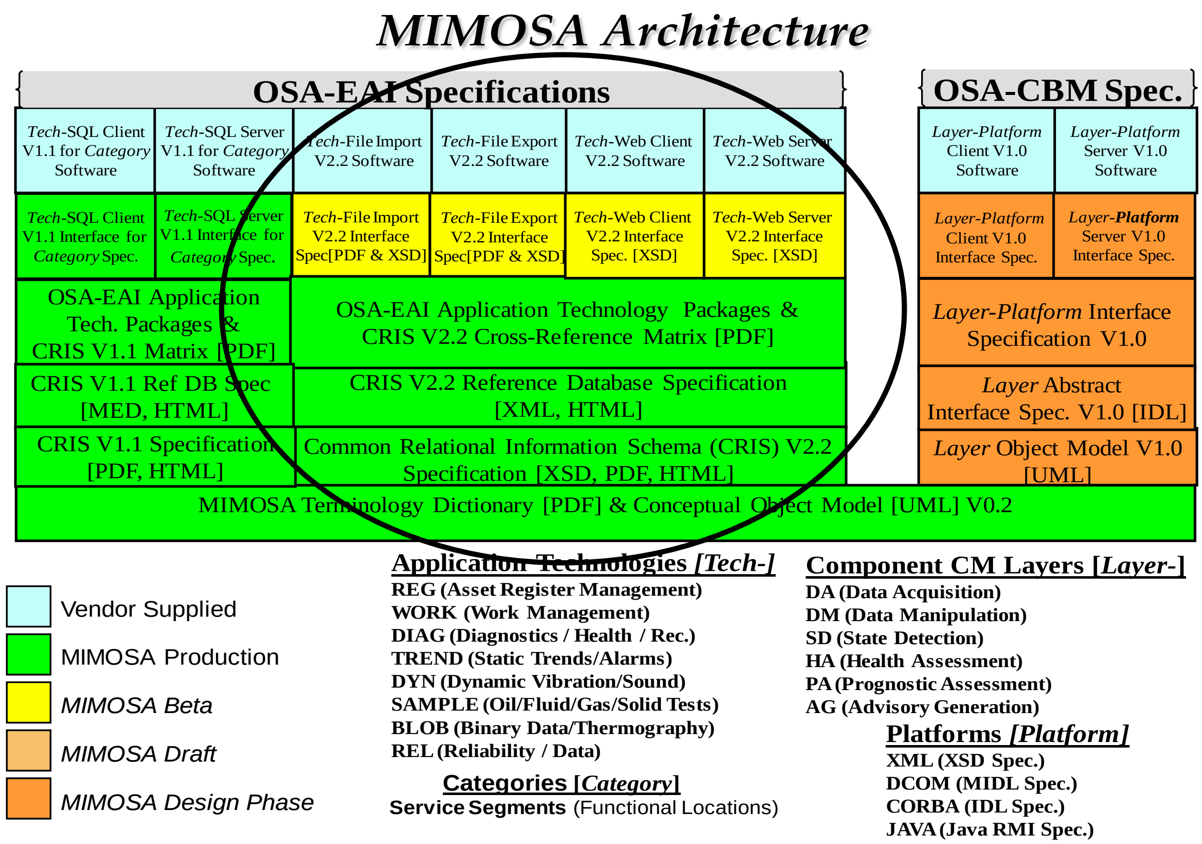

Figure B.2: Standards Architecture

Classifying the Application Architecture used for Army CECOM-Telemaintenance Demonstration according to the PCA-MIMOSA RAF:

Technology Configuration Dimension

- Platform Data Recorder (PDR) at PERA Levels 1 and 2
- Portable Maintenance Aid (PMA) at PERA Level 3
- Central Maintenance Aid (CMA) at PERA Level 4

Application Content Dimension

- Platform data sets for determining asset health, predictive analysis and decision support
- Platform work breakdown structure identification for appropriate association of condition, failure and maintenance records
- Platform work breakdown structure hierarchy information for aggregation of results to management.

Implementation Context Dimension

- Monitoring condition of military platforms for decision support on health management for existing assets

Service Agreement Model

- CECOM
- Platform CBM Suppliers

System Engineering Model

- PERA Levels 1 through 4
- MIMOSA Open Systems Architecture for Enterprise Application Integration (OSA-EAI)

Software Integration Model

- PDR stores operational and equipment monitoring data in MIMOSA Tech-File format and transfers to PMA and CMA
- PMA processes MIMOSA Tech-File and sends Work Request to CMA in a MIMOSA Work-Web Service
- CMA receives MIMOSA Tech-File and processes Work Requests from PMA to allow SME to assist in diagnostic/prognostic support
- CMA stores MIMOSA Tech-File in a MIMOSA OSA-EAI CRIS database

Semantic Ontology Model

- Terms from MIMOSA OSA-EAI Reference Data

Standards Usage Model

- MIMOSA OSA-EAI
- XML Schema
- WSDL/SOAP

Appendix C Integrated Engineering Asset Management

Figure C.1 illustrates the application architecture used across multiple projects operated by the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) for decision support of asset health management. In order to view this Application Architecture through the lens of the PCA-MIMOSA Reference Architecture Framework a summary of relevant information for the Reference Architecture Dimensions (RAD) and Reference Models (RM) is given below the figure.

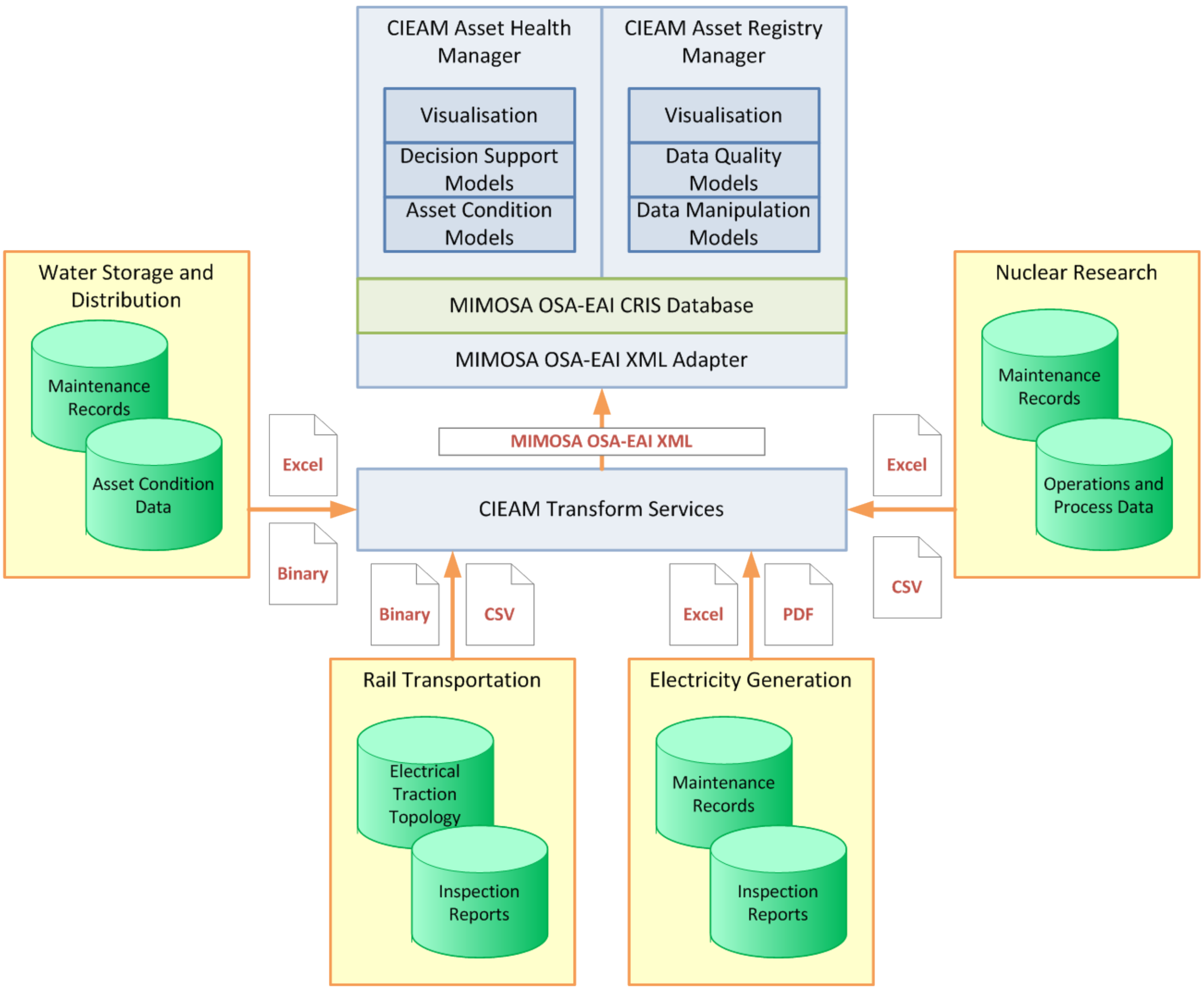

Figure C.1: Applications architecture for the CIEAM Asset Health Decision Support System

Classifying the Application Architecture used for the CIEAM Asset Health Decision Support System according to the PCA-MIMOSA RAF:

Technology Configuration Dimension

- Control and Monitoring Systems at PERA Levels 1 and 2
- Manufacturing Operations and Management at PERA Level 3
- Information System Applications at PERA Level 4

Application Content Dimension

- Data sets for determining asset health, predictive analysis and decision support
- Asset registry information for appropriate association of condition, failure and maintenance records
- Plant hierarchy information for aggregation of results to management.

Implementation Context Dimension

- Monitoring condition and operation for decision support on health management for existing assets

Service Agreement Model

- Multiple Owner/Operators
- Software Vendors

System Engineering Model

- PERA Levels 1 through 4
- MIMOSA Open Systems Architecture for Enterprise Application Integration (OSA-EAI)

Software Integration Model

- SCADA system produces operation and process data in a CSV format
- Portable data collector produces asset condition data in a binary format
- Maintenance management system produces in Excel format
- Document management system produces inspection reports in PDF
- Engineering design system produces electrical traction topology in a binary format
- CIEAM Transform Services transforms data into a MIMOSA OSA-EAI XML format
- MIMOSA OSA-EAI Adapter consumes XML for storage in a MIMOSA OSA-EAI CRIS database

Semantic Ontology Model

- Terms from MIMOSA OSA-EAI Reference Data

Standards Usage Model

- MIMOSA OSA-EAI
- XML Schema
- WSDL/SOAP

Appendix D Production Optimization

Figure D.1 illustrates the applications and application architecture involved in production optimization on the Norwegian Continental Shelf. In order to view this Application Architecture through the lens of the PCA-MIMOSA Reference Architecture Framework a summary of relevant information for the Reference Architecture Dimensions (RAD) and Reference Models (RM) is given below the figures.

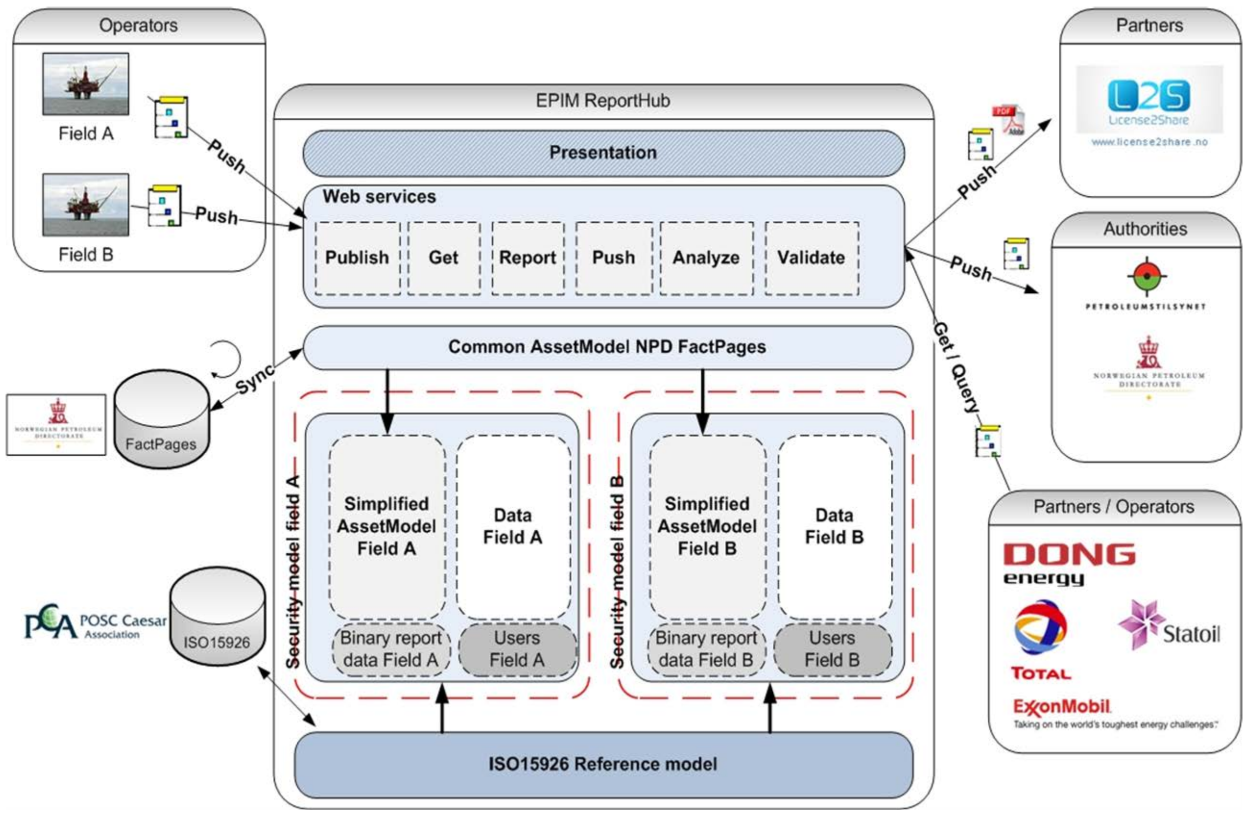

Figure D.1: Application architecture involved in EPIM Production Optimization

Classifying the Application Architecture used for EPIM Production Optimization according to the PCA-MIMOSA RAF:

Technology Configuration Dimension

- Information System Applications at PERA Level 4 and 5

Information Content Dimension

- Ontologies and reference data for oil & gas production and facilities
- Fact pages on oil & gas assets on the Norwegian Continental Shelf

- Fact pages on operator organization, location and compliance

Business Context Dimension

- Daily and monthly report on drilling and production must be delivered to the Norwegian authorities (Oljedirektoratet) by all operators on the Norwegian Continental Shelf.
- Drilling and production data is gathered and used to create the required reports
- The standard reports are encoded as XML using XML Schemas and delivered as required
- Custom reports can be extracted from available information for reporting to license partners

Service Agreement Model

Stakeholder Interest

- License operators, license partners, authorities (Oljedirektoratet, Petroleumstilsynet)

Business Models

- Drilling and production reporting to the Norwegian authorities is mandatory for all
- At this time the current ReportingHub is the only solution available for this reporting

Revenue Streams

- No direct revenue connected to this reporting (but the reported production volumes involve huge revenues for operators and license partners)

Cost Structures

- The cost of operating the ReportingHub solution is moderate and carried by EPIM (E&P Information Management) on behalf of all operators (but the reported drilling activity carries a huge cost for the operators and license partners)

Communication Behavior

- Standardized XML files posted daily and monthly

System Engineering Model

Operational Environment

- Solution running on the SOIL network operated and supported by RigNet.

Production System Configuration

- (Not applicable for this application – signals are delivered by standard low level systems)

Manufacturing Control Configuration

- (Not applicable for this application – control system data is delivered in structured form to other applications)

Information System Configuration

- Semantic technology (RDF, SPARQL and SPIN) used to extract and transform data
- XML and XSD is used to deliver data to users

Enterprise Integration

- Semantic Triple store and use of Reference Data in PCA RDL

<u>Software Interoperability Model</u>

Technology Platform

- SOIL network and services

Architectural Style

- Distributed web-based access to central storage

Programming Paradigm

- TopBraid Composer based on Eclipse IDE

Integration Mechanism

- SPARQL and SPIN

Data Storage

- AllegroGraph with hot standby

<u>Semantic Ontology Model</u>

Agreed Purpose

- Deliver accurate and timely reports on Drilling and Production activity to defined receivers

Defined Scope

- Daily Drilling, Daily Production, Monthly Production

Consistent Modeling Paradigm

- Reference Data Model according to ISO 15926 part 2

Uniform Modeling Constructs

- Reference Data Library according to ISO 15926 part 4

Reference Classes

- The PCA RDL includes all ISO 15926 Reference Data plus custom data based on ontologies developed specifically for ReportingHub

Standards Usage Model

Semantic Technology Standard

- W3C stack (URI, XML/ XSD, RDF/RDFS, SPARQL/SPIN, OWL)

Metadata Standard

- ISO 15926 Part 6

Data Quality Standard

- ISO 8000 compliant philosophy used

Data Security Standard

- Access and network security provided by SOIL

Reference Data Standards:

- ISO 15926

Appendix E Logistics Tracking

Figures F1 illustrates the applications and application architecture involved in tracking CCUs and equipment using RFID technology on the Norwegian Continental Shelf. In order to view this Application Architecture through the lens of the PCA-MIMOSA Reference Architecture Framework a summary of relevant information for the Reference Architecture Dimensions (RAD) and Reference Models (RM) is given below the figure.

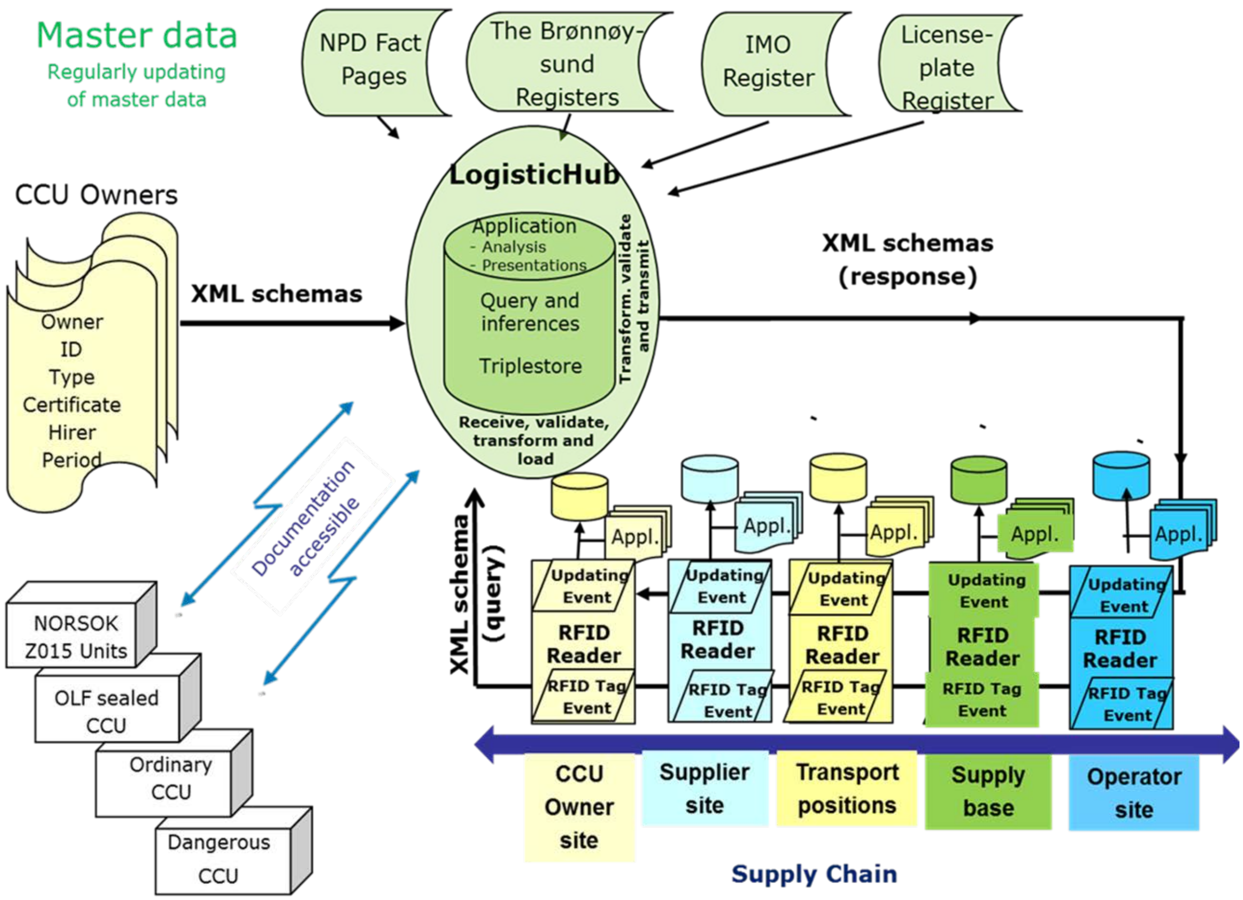

Figure E.1: Applications involved in EPIM Logistic Tracking

Classifying the Application Architecture used for EPIM Logistics Tracking according to the PCA-MIMOSA Reference Architecture Framework:

Technology Configuration Dimension

- LogisticHub is a database holding information generated by reading RFID tags (Level 1), processing associated events (Level 2) and storing it in a passing it through middleware (Level 3) to a semantic triplestore for use by web applications (Level 4).

Information Content Dimension

- LogisticHub involves information about events arising from loading, transporting and managing CCUs (Cargo Carrying Units) used in oil and gas production on the Norwegian Continental Shelf. The information shall be available on the Internet and shall include time, location and relevant details about all agreed events for all registered CCUs.

Business Context Dimension

- LogisticHub is meant to be used for all CCUs used for transport of equipment, goods and materials to and from all offshore platforms and facilities on the Norwegian Continental Shelf.

Service Agreement Model

Stakeholder Interest

- Operators will have better overview of where CCUs (and their contents) are located and reduce loss due to delayed return of leased equipment.
- Service companies will get better overview of the location and movement of CCUs (and their contents) and improve operational planning
- Equipment owners will get better overview of the location and movement of CCUs (and their contents) and improve tool utilization.
- Transporters will get better overview of the location and movement of CCUs and improve their scheduling, forwarding and freight times.
- CCU Owners will get better overview of the location of (all of) their containers and improve CCU utilization.

Business Models

- The stakeholders have different business models, but will all save cost and time through better information, allowing improved planning and utilization.

Revenue Streams

- No particular (new) revenue streams are expected associated with LogisticHub (but as noted above, the reduced cost and increased effectiveness of logistics planning and operation may be viewed as increased revenue).

Cost Structures

- The cost of developing the LogisticHub database and application will be shared by all members of the Norwegian Oil and Gas Association.

- The cost of installing an upgraded RFID system at offshore bases will be carried by the various owners of supply bases and CCUs (and be installed independently of LogisticHub).

Communication Behavior

- Since all communication will be between the individual stakeholders and (the shared) LogisticHub there are no particular new requirements to communication behavior, other than the need for CCU owners to (diligently) register all of their CCUs, and for all parties to ensure continuous and correct reading and reporting of RFID Tag event data.

System Engineering Model

Operational Environment

- RFID Tags placed on or inside CCUs travelling being shipped by truck and offshore supply vessels, and handled by cranes and fork lifts on supply bases and offshore facilities.

Production System Configuration

- Not relevant for the LogisticHub Database but data to be generated by RFID readers and tags and stored locally (Logical Memory Map, Device Drivers etc.).

Manufacturing Control Configuration

- Not relevant for the LogisticHub Database but data will be delivered via device controllers and middleware (translators, historians, etc.).

Information System Configuration

- Semantic Triple-store (RDF-triples) and associated applications for inputting event data and for various forms of querying about individual CCUs and aggregate information.

Enterprise Integration

- Stakeholders are connected to LogisticHub via Internet (https or other secure protocol).

Software Interoperability Model

Technology Platform

- SOIL network and services

Architectural Style

- Distributed web-services access to central storage

Programming Paradigm

- TopBraid Composer with Eclipse IDE

Integration Mechanism

- Restful Web Services and XML messages

Data Storage

- Oracle Semantic triple-store

Semantic Ontology Model

Agreed Purpose

- Store all captured business process events associated with CCUs moving through supply bases en-route to offshore facilities and arriving back from offshore facilities.

Defined Scope

- Business Process Events at supply bases for CCUs going offshore.
- Business Process Events at offshore facilities for CCUs arriving offshore.
- Business Process Events at offshore facilities for CCUs going onshore.
- Business Process Events at supply bases for CCUs arriving onshore.

Consistent Modeling Paradigm

- A uniform representation of event data (time, location, event type, CCU ID, etc.) according to a process model developed by DNV.

Uniform Modeling Constructs

- Reference Data classes instantiated from ISO 15926 Part 2 and included in PCA RDL.

Reference Classes

- ISO 15926 ontology and reference data for CCUs developed by PCA.
- ISO 15926 ontology and reference data for AIDC systems to be developed.

Standards Usage Model

Semantic Technology Standard

- SPARQL, RDFS/OWL, RDF, XML.

Metaata Standard

- ISO 15926 Part 6.

Data Quality Standard

- N.A. (internal quality control during development)

Data Security Standard

- SOIL, LDAP.

Reference Data Standards

- ISO 15926, GS1/GSN.

Appendix F Relevant Standards and References

A large number of standards exist addressing automation and control of IT and enterprise architectures. A selection of relevant standards and reference models is given below.

IEEE 1471 (IEEE Recommended Practice for Architectural Description for Software-Intensive Systems) is an IEEE Standard for describing the architecture of a software-intensive system, also known as software architecture. It has been superseded by ISO/IEC/IEEE 42010:2011, Systems and software engineering – Architecture description.

ISO 13374-2 (Condition monitoring and diagnostics of machines – Data processing, communication and presentation) details the requirements for a reference information model and a reference processing model to which an open condition monitoring and diagnostics (CM&D) architecture needs to conform. Software design professionals require both an information model and a processing model to adequately describe all data processing requirements. ISO 13374-2:2007 facilitates the interoperability of CM&D systems.

ISO 14258 (Concepts and Rules for Enterprise Models) defines "the elements to use when producing an enterprise model, concepts for lifecycle phases, and how these models describe hierarchy, structure, and behavior". Also contains guidelines and constraints for relating the real world to enterprise models through views. This latter concept is equivalent to the views of ENV 40003.

ISO 15704 (Requirements for Enterprise Reference Architecture and Methodologies) attempts to place the concepts used in methodologies and reference architectures such as ARIS, CIMOSA, GRAI/GIM, IEM, PERA and ENV 40003 within an encompassing conceptual framework that allows the coverage and completeness of any such approach to be assessed. It draws heavily on the work of the IFAC/IFIP Task Force on Enterprise Integration and previous work from Purdue University.

ISO 15926 (Industrial automation systems and integration – Integration of life-cycle data for process plants including oil and gas production facilities) specifies a representation of information associated with engineering, construction and operation of process plants, supporting information requirements of the process industries in all phases of a plant's lifecycle. Information concerning engineering, construction and operation of production facilities is created, used and modified by many different organizations throughout a facility's lifetime. The purpose of ISO 15926 is to facilitate integration of data to support the lifecycle activities of production facilities.

ISO 18435 (Industrial automation systems and integration – Diagnostics, capability assessment and maintenance applications integration) facilitates interoperability by defining a set of integration models and interfaces based on the enterprise-control system integration approach of ISO/IEC 62264 (ISA-95) and emerging standards for condition-based monitoring (ISO 13374).

IEC 62264-1 (Enterprise-control system integration) describes the manufacturing operations management domain and enables integration between the manufacturing operations and control domain (Levels 3, 2, 1) and the enterprise domain (Level 4). Its goals are to increase uniformity and consistency of interface terminology and reduce the risk, cost, and errors associated with implementing these interfaces.

Similarly, a list of relevant reference architectures and frameworks includes:

Purdue Enterprise Reference Architecture (PERA) was developed by the Purdue Laboratory for Applied Industrial Control at Purdue University as part of the work of the industry - Purdue University consortium for CIM. The Purdue reference model started in 1986. The PERA Reference Architecture and methodology provides the necessary guidelines for the integration of applications (tools) through all the phases of an integration program from initial concept through use to final decommissioning. It considers the full lifecycle of the enterprises

Generalized Enterprise Reference Architecture and Methodology (GERAM) is a generalized Enterprise Architecture framework for enterprise integration and business process engineering. It identifies the set of components recommended for use in enterprise engineering. It was developed in the 1990s by an IFAC/IFIP Task Force on Architectures for Enterprise Integration. The development starting with the evaluation of existing frameworks for enterprise integration which was developed into an overall definition of a so-called "generalized architecture", which was named GERAM for "Generalized Enterprise Reference Architecture and Methodology".

The Open Group Enterprise Architecture (TOGAF) is a framework for enterprise architecture which provides a comprehensive approach for designing, planning, implementing, and governing enterprise information architecture. TOGAF is a registered trademark of The Open Group in the United States and other countries. TOGAF is a high level and holistic approach to design, which is typically modeled at four levels: Business, Application, Data, and Technology. It tries to give a well-tested overall starting model to information architects, which can then be built upon. It relies heavily on modularization, standardization and already existing, proven technologies and products.

Federal Enterprise Architecture Framework (FEAF) is the enterprise architecture of a federal government. It provides a common approach for the integration of strategic, business and technology management as part of organization design and performance improvement.

Finally, an overview of the standardization activities addressed by ISO TC184 with an indication of the corresponding ISA-95 (ISO 62264) levels addressed by the resulting standards from the various activities is shown in Figure F.1.

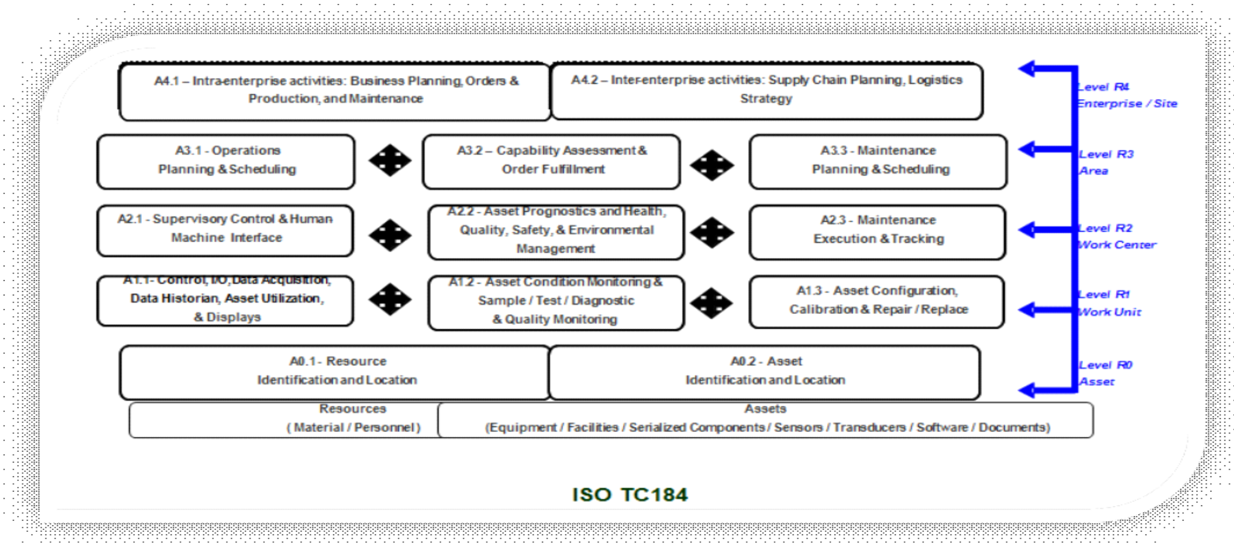

Figure F.1: ISO TC184 activities and corresponding ISA-95 (ISO 62264) Levels

For an overview of Enterprise Integration Standards see “International Standards for System Integration” by Richard A. Martin[2].

[2] http://www.tinwisle.com/iso/RM_SME_SUMMIT05.pdf