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Enterprise Integration of Engineering Systems for Defence Related Projects

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Abstract. Defence Projects world-wide are undergoing a gradual transition from development projects to those involving integration of COTS and Military-Off-The-Shelf (MOTS) Systems. At the same time Requests for Tender (RFT) solicit Innovative Support Solutions to reduce Life Cycle Cost (LCC) over thirty years of operation. While there are defined processes to support both Systems Engineering and Support Engineering, these are hierarchical by engineering discipline and do not provide the means of architecting and trading off system design and support objectives concurrently. This study analyses the suitability of existing engineering processes and builds a model of the current state process set and artefact relationship and compares these with the international standards against the goals of reduced Life Cycle Cost (LCC). This reserach identifies the transitional needs and proposes changes to the Enterprise Business Management System processes, tools and work product templates to achieve concurrent system and service solution engineering.

Keywords. Enterprise integration, product service systems, commercial-off-the-shelf, military-off-the-shelf, life cycle cost, support solution

Introduction

Australian Defence Force Projects are undergoing a gradual transition from new development projects to those involving integration of commercial-off-the-shelf (COTS) and military-off-the-shelf (MOTS) systems [1], at the same time requests for tender (RFT) solicit innovative support solutions to reduce life cycle cost (LCC) over the service life, typically over thirty or more years of operation. While there are defined processes to support both systems engineering and support engineering, these are hierarchical by engineering discipline and do not provide an efficient means of architecting and trading off system design and support objectives concurrently. Often shortfalls of acquisition funding limit the adequacy of the support solution to sustain the system.

Current government thinking is to enter into performance based contracts to engage a prime contractor, that is fully responsible for managing all relationships with suppliers and sub-contractors. However, research has shown that effectiveness of this type of contracts depends on the relationship and system compatibility between customer and suppliers. The result is the risk of uncertainty in guaranteeing availability and capability of the system being support [2]. For example, the Hobart Class Air

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Warfare Destroyer (AWD) requires a well-defined support architecture for through life support system due in part to the complexity of the ship and partly due to the large number of stakeholders that need to interact to create an effective support solution for the systems [3].

This paper discusses an enterprise integration approach to adapting commercial organization internal systems to manage defence related projects in such a volatile environment is a complex and time consuming exercise as it involves multiple stakeholders, an understanding of the processes, determination of the requirements of the organisation and knowledge of available system models for supporting military asset's 30 year in service life.

1. Review of Current Enterprise Models

Enterprise models require an architecture framework to provide the foundation structure and constructs to build. The following literature review focuses on some of the common architectures used in industry and government agencies.

1.1. Department of Defence Architectural Framework (DoDAF)

The initial literature review identified that the US Department of Defense Architecture Framework (DoDAF) was popular, with some work further into Human Views including the NATO Human View [4] to complement Operational, System and Service Views. There are papers on specific uses of DoDAF to solve problems such as Information Security [5,6] and System Integration [7,8]; but little available as examples of service-system integration.

The DoDAF is the overarching, comprehensive framework and conceptual model enabling the development of architectures to facilitate the ability of US Department of Defense (DoD) managers at all levels to make key decisions more effectively through organized information sharing across the Department, Joint Capability Areas (JCAs), Mission, Component, and Program boundaries.

DoDAF serves as one of the principal means supporting the DoD under the Clinger-Cohen Act for the development and maintenance of information architectures [9]. The Act defines the term "information architecture" as an integrated framework for evolving or maintaining existing information technology and acquiring new information technology to achieve the agency's strategic goals and information resources management goals.

1.2. AUSDAF

Zhu et al [10] applied the Australian Defence Architecture Framework (AUSDAF), a variant of DoDAF to software system architecture. Architecture Evaluation is an approach for assessing whether a software architecture will be complete and consistent in terms of the system needs, especially the non-functional requirements (also known as quality requirements). Architecture Evaluation can be used at different stages of a project, and is an effective way of ensuring design quality early in the lifecycle to reduce overall project cost and to manage risks.

1.3. United Kingdom Ministry of Defence Architectural Framework (MoDAF)

The UK Ministry of Defence (MoD) Architectural Framework (MoDAF) [11] contains seven viewpoints: (1) All Views; (2) Strategic Views; (3) Operational Views; (4) System Views; (5) Service Oriented Views, (6) Acquisition Views, (7) Technical Standards Views. Key to this framework is the support for service information systems needed to support the operational system. The usefulness of these evolved frameworks may be limited as many of the adaptations have been incorporated into later versions of DoDAF.

1.4. TOGAF

The Open Group [12] produced the original version of TOGAF in 1995, based on the Technical Architecture Framework for Information Management (TAFIM), developed by the US Department of Defense (DoD). Enterprise Architecture can be used to denote both an entire enterprise - encompassing all of its information and technology services, processes, and infrastructure.

1.5. Interchange between Architectural Frameworks and Models

An issue with architectural frameworks is that their data models are extendable and may be implemented differently by different tool vendors who apply their selected methods. To transport architectural models between organisations it is necessary to align both the framework and the underlying data model. DoDAF OWL is the interchange specification for the DoDAF DM2 data model.

The Unified Profile for DoDAF and MoDAF (UPDM) is an evolving interchange standard for graphical interchange as well as current textual (XMI) interchange method. This method enables UK enterprises using MoDAF to exchange architectural information with US using DoDAF [13].

1.6. BAE Systems Enterprise System Processes

The Business Management System (BMS) in BAE Systems Australia is based on a combination of Life Cycle Management (LCM) a BAE Systems Project Phase/Gate Methodology, the Australian Standard for Defence Contracting (ASDEFCON) and the System Engineering Life Cycle Model (V-Model) organized by the ISO 15288 Process Areas. This approach considers the primary processes to be those required to produce a Mission System as well as those to develop the Support System. It should be noted that the BAE Systems definition of Product does not differentiate System and Service and it intended that the defined processes support either.

1.7. Stakeholder Analysis

Experience from recent bidding activities shows continued observations that the Support Team and Systems engineering teams work in isolation and information transfer takes place too late in the tender cycle. Consideration of the support solution is included but due to lack of understanding of the implications of performance based contracting, many contracts were made with a lot or risks [14]. Hence, the External

Stakeholder analysis was performed as a documentation analysis activity rather than through direct access to these stakeholders. This limitation was mainly because of resource and time limitations on this project (Figure 1).

Stakeholders that can be identified through this analysis include:

- The General Public – While the general public is not identified as a process stakeholder, the general public and its special interest groups have impact on the operations and support of defence products and services.
- The Warfighter – The user of the defence products is collectively termed the "warfighter" as the front line operator/maintainer/supplier of the product or service system. The warfighters opinions of fitness for purpose may be represented through official defence, political or media channels.
- Capability Acquisition and Sustainment Group – The Defence Materiel Organisation (DMO) was the contracting organisation of the Australian Government and managed the contractors such as BAE Systems for all Australian Defence project portfolio.

Stakeholder	Relationship	Key Needs	Interest Intensity	Influence /Power	Proximity	Urgency	Engagement Strategy
Warfighter	Operator/End User First Level Maintainer	Availability Reliability Timely Ease of Use	Highly affected by quality of support	Indirect but have influence via media	Distributed across Australia & Globally	High, Real-Time Issues	Voice of the Customer
Capability Acquisition & Sustainment Group	Capability Architect Acquirer	Performance Based Contracting	High Interest in Life Cycle Cost	High – Contracting Authority	Canberra Based	Low – long timeframes	Integrate Architecture Tailoring of ASDEFCON
System Project Office	Project Office Support Agency	Sustainment, Lice Cycle Cost, Upgrade,	High Interest in Cost and Schedule	Medium – Execute Contracts	Located on bases across Australia	Medium – Project Capability Timescales	Integrate with Architectural Systems Tailor Templates
Prime Contractor	System Architect /Supplier	Requirements Acceptance	Highly affected by OEMs	Control over Solutions	Typically Australian based	Medium – Project Contracted Timescales	Lead System/Service Architecture
Original Equipment Manufacturer	Supplier of Subsystems	Subsystem Requirements, /Acceptance	Low – Existing Customer Base	Control over Product & Data	Distant – Typically US or Europe	Low – Established Products and services	Obtain Product Data in format needed to perform analysis
Service Provider	Provide Services to Prime/OEM	Performance Criteria	High – Meet Performance Criteria	Control over response times	May be	High – Real time issues	Characterise Services

Figure 1. Stakeholder Engagement Analysis.

- Subcontractors – Subcontractors required to provide allocated subsystems of the Mission and Support Systems through a contract with the Prime Contractor. BAE Systems may perform the role of either a Prime Contractor or Subcontractor depending on the scope of the project.
- Service Providers – Service providers may be engaged as part of the Support Project or already exist as part of an ongoing support arrangement. These service providers require the skills to operate support processes as well as a means of improving their quality etc.

Further work could include direct external stakeholder engagement by interviewing representatives of each external stakeholder group.

1.8. Project Analysis

Project lessons learnt are a set of repositories of Learning From Experience (LFE) documents stored on the company central database. These are documented as both "positives" or best practices as well as "negatives" or things to avoid. The intention of these documents is to inform future bids/projects as well as provide input into improvement mechanisms. The following were extracted from the LFE documents:

Research shows that there is a market transition taking place along the Product-Service evolution towards servitisation [15]. New product development continues as does the need to support legacy systems. New defence projects either replace existing systems or undergo modification to achieve new capabilities or reduce life cycle cost. Traditionally, Acquisition and Support projects are separated, with the Logistic Support Analysis Report (LSAR) being the key artefact linking the two projects. Where both Acquisition and Support was performed by the same organisation, inadequacies of logistic support data could be remedied by the same organisation. Where they are separated, data deficiencies are exposed and may not be supported by Intellectual Property agreements.

For the purpose of analysis the projects have been categorised into four types to test the adequacy of Systems Engineering and Support engineering capability. Table 1 identifies these four types of projects and their relationships with different types of systems.

Table 1. Analysis of Project Types.

Case	Misson system	Support system	Support service	Opportunities
Developmental Mission and Support System	New Development Mission System	New Development Support System	New Support Service	Architecture Driven Performance Based
Unmodified MOTS	Unmodified Mission System	Unmodified Support System	Unmodified Support Service	Limited by Legacy Arrangements
Modified COTS/MOTS	Modified COTS/MOTS	Adapted Support System	Adapted Support Services	Reduce Life Cycle cost
Sustainment Only	Existing	Existing	Innovative Support Solutions	Reduce Support Cost

1.9. Process Relationship Modelling

There are numerous methods of defining and representing process. The common features of these representations are that they in some way describe activities to varying extents. Due to the different ontologies used to define process, this study was presented with a challenge of how to:

- Show that process elements are related to each other, even though they are described differently
- Understand the extent to which the existing defined processes work together or 'integrate' to achieve a common purpose.

For the former, the methodology selected to compare processes was the Supplier Input Process Output Customer (SIPOC) method from Six Sigma [16]. The extent to which processes are integrated involved the categorisation of the maturity of integration using Integration Readiness Levels (IRLs) by considering the process structure as a system and linkages between processes as interfaces. The quality of

process integration was assessed using the criteria known as Integration Readiness Level [17].

1.10. Analysis of ASDEFCON

A SIPOC analysis was performed to identify relationships of ASDEFCON with BAE Systems BMS processes. This is needed as the ASDEFCON templates form the basis of the Contract Data Requirements List (CDRL) on a contract.

Since ASDECON was the customer's template, it was not feasible to directly relate to the BAE Systems Process. The SIPOC process representation was used to create "process equivalence". The analysis was performed on a small number of items to determine the extent of linkage between data items. The literature review did not discover any overall architectural framework under which ASDEFCON is defined. This does not mean it is non-existent, but further work may be needed in conjunction with the Department of Defence to establish whether such an architecture exists and whether it is maintained. In the absence of the availability of.

1.11. Analysis of Architectural Frameworks

To develop a specific enterprise model, reference to an existing proven architectural framework can improve the chance of success. In the United Kingdom the MoDAF provides the architectural framework for both acquisition and support. The UK Logistic Coherence Information Framework (LCIA) is expected to interact with MoDAF and provide a common set of processes and work products across both Government and the Defence Industry. The LCIA process structure covers the Systems Engineering and Support Engineering processes for both acquisition and sustainment.

In Australia, there does not appear to be any equivalent policy to either UK or US that would either mandate the use of architecture or provide the means of transfer of architectural information between the Acquirer (CASG) and the Australian Defence Industry Supplier.

2. Observations

The theoretical frameworks reviewed so far are required to be matched with existing engineering system processes [19] for transitioning. The following section describes some observations that can affect the implementation.

2.1. Architectural Observations

Large US based programs such as the Joint Strike Fighter (JSF) are mandated to use DoDAF. During the Tender activity it is difficult to maintain coordination between the development of the product solution and support solution. Architectural Design is a supported BMS process but is not well supported with tools/methodology and training, particularly in Support Engineering.

The customer of BAE Systems Australia is primarily the Australian Department of Defence with most projects contracted through the Capability Acquisition and Sustainment Group (CASG) using tailored versions of the ASDEFCON, which

stipulated the content of external deliverables in the form of contract data. CASG produces Operational Concept Documents (OCDs). However, this approach focuses on the Mission System Capability rather than Support System or sustainment services. The Core/WSAF Model is not made available to Defence Contractors and "reverse engineering" to expose model relationships is incomplete.

2.2. Engineering Lifecycle Observations

Projects are expected to tailor the organisational common processes to suit their needs. This is expected to be through the approval of engineering plans. The Systems Engineering processes are defined around the V-Model Engineering Lifecycle. While these may be suitable for "greenfield" development projects they do not meet the needs of "brownfield" projects where segments of both mission and support systems may already exist and require integration and transition to sustainment.

The Commonwealth provided Statement of Work explicitly defines the required engineering phases and mandated reviews. For "brownfield" type projects the use of development oriented phases and reviews requires tailoring for recognition of previously developed product and service.

For service projects performing Engineering Support on developed and fielded systems projects extensive tailoring of process is required. The Engineering Support Process adequately address the range of Engineering process required to perform Engineering as a service.

2.3. Engineering Information Systems Observations

Engineering Information Systems are in place for Requirements Management and Configuration Management. There is a common data schema for Requirements Management (DOORS Schema). There is opportunity to extend the DOORS Schema into architecture and logistics information systems to suit Australian Defence requirements.

3. Proposed Architectural Approach

According to Harrison [20], architecture must have purpose. The architectural element of this framework considers architecture to be a whole of life concept rather than a phase within the engineering development activity. Architecture would be developed and maintained for different purposes. Elements in this architecture are:

- Business Strategy – The Business Strategy element of this architectural approach is aimed at aligning the enterprise to the business objectives, defence or other business Sevicescape, criteria for making decisions and understanding of assumptions and constraints. These collectively form the basis for ongoing project activities. The business strategy is supported by a Business Model, Business Data and the capability to perform business analysis.
- Characterisation of Existing Capabilities – For existing systems the architectural approach is to either integrate existing models or to "reverse engineer" existing products or services to be able to evaluate against the

capability architecture. Previous Verification and Validation data is used to determine fit to the capability architecture.

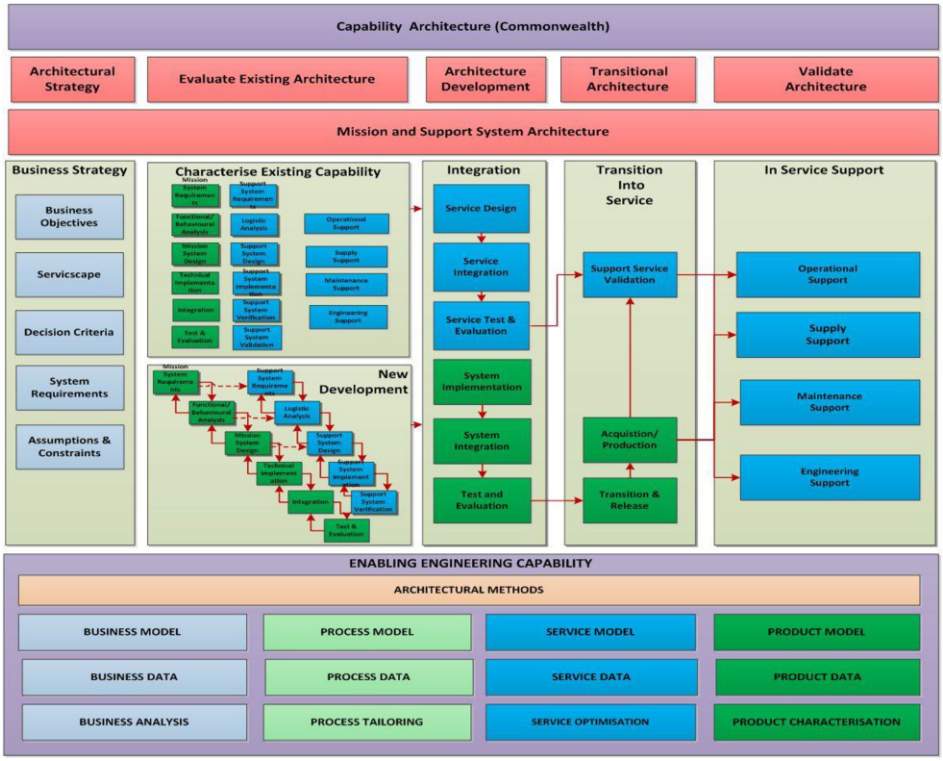

Figure 2. Proposed Architectural Approach.

- Integration – Once characterised and accepted as suitable, the products/services undergo adaptation and integration into the required product-service system. The maturity of this integration is measured through Integration Readiness Levels. Any new development elements are integrated with the adapted elements to form the new systems.
- Transition Into Service – The transition into Service utilises Project Views of Architecture to schedule the requisite elements of products and services for deployment and use. At this stage the product-service systems are used in their intended environment and undergo validation against the capability architecture.
- In Service Support – Throughout the sustainment period, product and service measures are captured and analysed against the metrics design to support performance based contracting requirements and form the basis of process improvement. Progressively, the capability architecture, system and service models are validated. As changes are undertaken the architecture and models are updated. Any potential change can be modelled prior to commitment to change to ensure changes will contribute to lower life cycle cost.
- Enabling Engineering Capability – The architectural approach requires the deployment of architectural frameworks, models and engineering systems as an integrated data system governed by a data schema. This is necessary to

ensure interchange of information between the architecture, models and metrics systems.

4. Conclusion

The proposed architectural approach provides a clear development pathway for migrating existing engineering system processes to a new support system architecture that is complete and adaptable. With change of project types from predominantly new development projects to a mix of new and existing system integrations and service projects, the approach to selection and deployment of Engineering lifecycle should reflect this change through de-emphasising the V-Model approach and forming new project templates based on project characteristic. Alternative engineering life cycles such as the spiral or incremental model should be supported by process, tools and training.

To facilitate the transition to servitisation, the project characterisation should allow for the response to be by the selection of services from the service process library. If product development is required, this could be accommodated through the use of a "product development service" In this way the distinction between a product and service can be applied at the appropriate level of the Work Breakdown Structure.

While it is expected to be significant variations in Mission System architectures, Support System and Support Service architectures for Defence align with the constituent support capabilities. An architecture template for support, consistent with the ILS Work Breakdown Structure (WBS) would allow current projects to initiate an architected support solution which can be linked to the Mission System architecture. From this early use of support architecture, successive projects could then evolve and improve the architecture to suit typical support solutions.

The Role of Solution Architect needs to be developed and skilled to the point where there are competent persons capable of applying Systems Thinking to the capability problem-space and generate the Product-Service architectural models can be used to support servitisation decisions at the early stages of a project, at least before any design decisions are made.

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