Demonstrating Model-Based Systems Engineering for Specifying Complex Capability

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Abstract. Model-Based Systems Engineering (MBSE) is a methodology for, but not limited to, scoping system definitions, articulating needs and deriving requirements for a new capability. This methodology focuses on developing a model of the architecture of the system rather than documentation. At any point during the programme's lifecycle, the knowledge captured within the model can be exported to produce desired documentation. This allows for significant benefits over the traditional document-based approach including improved robustness and traceability to capability needs and client requirements and retention of knowledge in the model. This approach is employed in the Defence Project LAND19 Phase 7 (Ground-Based Air and Missile Defence), which aims to deliver a complex capability and is in its preliminary phase. The programme has employed MBSE to produce the Preliminary Capability Definition Documentation (PCDD).

This paper describes a MBSE methodology developed for the creation of the PCDD for LAND19-7 and identifies recommendations for further development.

INTRODUCTION

Defence has introduced the Defence Architecture Framework (DAF) (Defence 2009a) embodying the Enterprise Architecting (EA) methodology into the capability definition process. (Robinson & Graham 2010) suggested significant benefits derived from extending this approach to plan capability project analysis requirements. The presented work extends this application to Model-Based Systems Engineering (MBSE) for capability definition including production of capability definition documents.

MBSE is an emerging discipline that uses the development of a model to represent the problem-space and to define the parameters of the system of interest. This approach can be used to support the capability life cycle. It can be characterised as "...the collection of related processes, methods, and tools used to support the discipline of systems engineering in a 'model-based' or 'model driven' context." (INCOSE 2008).

MBSE has been applied to Project LAND 19, Phase 7 (LAND 19-7) which seeks to develop the Australian Defence Force's (ADF) future Ground-Based Air and Missile Defence (GBAMD) capability. The project is currently in the process of defining the capability requirements which involves the development of the Preliminary Operational Concept Document (POCD), Preliminary Functional and Performance Specification (PFPS) and the Preliminary Test Concept Document (PTCD)[1].

In a departure from the document-centric approach to capability definition currently favoured in Defence, MBSE was used to model

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1. The PTCD will be similarly generated following the completion of technical risk assessments and finalisation of the measures of effectiveness and suitability and the subordinate measures of performance. The POCD and PFPS were produced to demonstrate the feasibility of applying MBSE to capability development and to gain support for this approach within Defence.

the GBAMD capability enterprise architecture (and its external interfaces). The LAND 19-7 POCD and PFPS were then generated as artefacts from this architectural model. The production of these documents, while not strictly necessary under a genuine MBSE regime, is mandated by Defence as part of the approved capability development process. The authors consider the ability to support and improve the existing process to be a required first step in gaining Defence acceptance for the adoption of MBSE throughout the capability life-cycle. This method and its benefits are outlined in this paper.

DSTO support to capability definition. A major role of the DSTO is to undertake analysis supporting the introduction of complex capability into Defence service. The increasing complexity of defence capabilities and the environment in which they operate, drove the need for a holistic, more robust approach to capability analysis. The Whole-of System Analytical Framework (WSAF), in an innovative approach, was developed to meet this challenge (Robinson & Graham 2010) and is based on established EA and systems engineering principles and DAF guidance (Defence 2009a).

The success of employing the WSAF in the analysis domain, encouraged the LAND 19-7 project team to extend the WSAF to develop GBAMD capability requirements and produce Capability Development Documentation (CDD) (DMO 2009a) for the project. The WSAF approach employs client and systems definition language, engineering rigour and the DAF; all of which are key requirements for the generation of the OCD and FPS documents. With minimal adaptation, the WSAF has been developed to include the information and support required for the generation of POCD and PFPS for LAND 19-7 using an approach underpinned by MBSE principles and methods. Hence, the present work has grown the WSAF into an enhanced instantiation of MBSE to include operational and physical interface and life-cycle support requirements. A direct outcome has been the increased integrity in the resulting LAND 19-7 CDD and stronger and more purposeful stakeholder engagement.

Lessons from previous projects. The following lessons are a compilation derived from experiences by the authors of numerous projects over many years and have led to the search for a better way of doing business:

- **Poor knowledge capture and retention.** The time from the needs phase to acquisition and introduction into service of major capital equipment projects can exceed ten years. Over that time there can be significant staff turnover potentially resulting in substantial knowledge loss, unless there is an effective means for capturing and retaining it. Knowledge that is lost usually includes the rationale behind past decisions and technical information that may reside deep in files or numerous reports. The consequence for new staff is that they can expend significant time in recreating or rediscovering lost knowledge leading to frustration and resource wastage. Where key documents such as the OCD and FPS are modified over time, maintaining the integrity of these documents is difficult in the absence of a continuation of knowledge.

- **Inadequate articulation of user needs.** Any gaps or inadequacy in user needs is often discovered belatedly, necessitating urgent corrective action under severe time pressures when preparing the FPS for release with a Request For Proposal (RFP) or Request For Tender (RFT). An inadequate user requirement set is normally a result of a lack of rigour in the development of user needs.

- **Poor framing of issues and measures.** COIs translate into Measures Of Effectiveness (MOEs), Measures Of Performance (MOPs) and Measures Of Suitability (MOSs) for the capability system and its use that form the basis for the development of the Test Concept Document (TCD) and in turn the Test and Evaluation Master Plan (TEMP). In the past, problems such as poor framing of COIs including having significant critical issues overlooked and too much overlap between COIs have been discovered belatedly during contract negotiation making negotiations difficult and necessitating a significant amount of rework prior to contract award.

- **Poor requirements framing.** The specification of functional requirements should involve Subject Mater Experts (SMEs) who assist with the correct articulation of technical and operational requirements and can advise on the appropriate interaction of related requirements. It should also involve a rigorous requirements capture process to minimise gaps or conflicts in the requirement set. Gaps, conflicts and inadequate understanding of the inter-relationship of requirements have been experienced in the past. When coupled with staff turn-over and an inadequate continuation of knowledge over time, these issues have led to these significant problems:

  – **In tender evaluation.** Late night debates among the evaluation team about what the requirement really means. In extreme circumstances this can potentially lead to an unsound source selection decision.

  – **In contract negotiation.** Poor understanding of the decisions made in defining a requirement can place project staff in a weak negotiating position and increase project risk.

  – **Poor practices.** Under the pressure of time or when lacking expertise, project teams often resort to using previous 'good example' OCDs and FPSs as templates for their project and resort to 'cutting and pasting' in order to make up for deficiencies in time, expertise and knowledge. While expedient, this approach perpetuates errors and bad practices that can result in the problems discussed previously.

  – **Poor analytical focus.** Major Defence projects have substantial science and technology resources assigned to them and also often engage experts outside of Defence to conduct specific studies the results of which can be used to analyse risk, inform requirements definition or to support source selection. Identifying the specific study questions and the prioritisation of scarce resources is always the subject of active debate. This is especially the case where various technical SMEs have divergent interests and divergent ideas of what is important. Poor analytical focus may waste time and other resources and can result in vital information not being available when needed.

These deficiencies can result in higher project acquisition costs due to the Defence project team being in a weak negotiating position during contract negotiation. In addition, unexpected project delays and cost increases may result from the belated discovery of problems after contract award.

MBSE

Model-Based Systems Engineering (MBSE) is gaining popularity in the Systems Engineering community to support product life cycle. It focuses on the development of an abstraction, or model, of the system of interest to support the Systems Engineering process. (INCOSE 2009) describe MBSE as '…collection of related processes, methods, and tools used to support the discipline of systems engineering in a 'model-based' or 'model driven' context.' They go onto to say that MBSE '…is about elevating models in the engineering process to a central and governing role in the specification, design, integration, validation, and operation of a system.'

This section highlights the salient points appropriate to the development of the capability definition documentation and the application of the WSAF to MBSE. The reader should refer to INCOSE's survey of MBSE methodologies (INCOSE 2008) for further reading.

Requirements for MBSE. By definition, the method of MBSE relies on the development of a central model that captures the specification of the complex system under investigation. There are number of considerations for the development of a model, from the modelling language to the paradigm for its development. These are not discussed here as they are defined later in the paper. Instead consideration is given to the definition and discuss of the requirements for the model. (Ogren 2000) indicates that there are five key requirements of the model:

  – **Determinism with formality.** This means that everything expressed in the model must have a single, defined and obvious meaning.

– **Understandability.** Since systems engineering should be done in close cooperation with end-users, the models used must be readily understood, without extensive education or experience in software or mathematics.

– **Inclusion of system missions.** The model must elicit the systems missions and also be able to express how different parts of the system contribute to completion of these missions.

– **Modelling of structure and behaviour.** The modelling technique shall support splitting a system into subsystems, with clarification of interfaces between these systems, and the modelling technique shall also allow definition of behaviour within the subsystems defined.

– **Possibility of verification support.** It shall be possible to verify a completed model. This verification can be against defined requirements, but it can also concern verification of completeness, consistency, etc. For complex systems, verification will often require computer support, depending on the amount of information to be managed.

These requirements need to be adhered to in the development of the model for an MBSE approach.

MBSE Survey. (INCOSE 2008) has undertaken a comprehensive survey of MBSE approaches. Of these, one approach identified by INCOSE, is the Vitech MBSE methodology. With the WSAF utilising CORE ® (Vitech 2009) for the definition of analysis requirements (Robinson & Graham 2010), the Vitech MBSE methodology guides the application of the WSAF for MBSE.

According to Vitech (Vitech 2009) a system development programme can be split into four activity domains; requirements, behaviour, architecture, and verification and validation. An MBSE approach, using Vitech's CORE®, affords significant and effective communication between all four domains and stakeholders. The Vitech approach is to employ CORE environment to design and develop the system definition in a 'system design repository'. This repository spans all four domains activity domains allowing for constructing, storing and verifying the system model and generating appropriate design documentation. The integrated system model, stored in the repository, generates stakeholder views and artefacts thus enhancing communication between stakeholders and allowing critical insights into the system interactions. The Vitech MBSE approach is depicted in Figure 1.

As described in the following sections, CORE is not the only product appropriate for use in MBSE. Several alternative software tools are available, each with its unique advantages and disadvantages. However, the WSAF had been constructed utilising CORE and staff were familiar with its workings. As such CORE represented the lowest schedule risk to LAND 19-7 and so was adopted in extending the WSAF to MBSE.

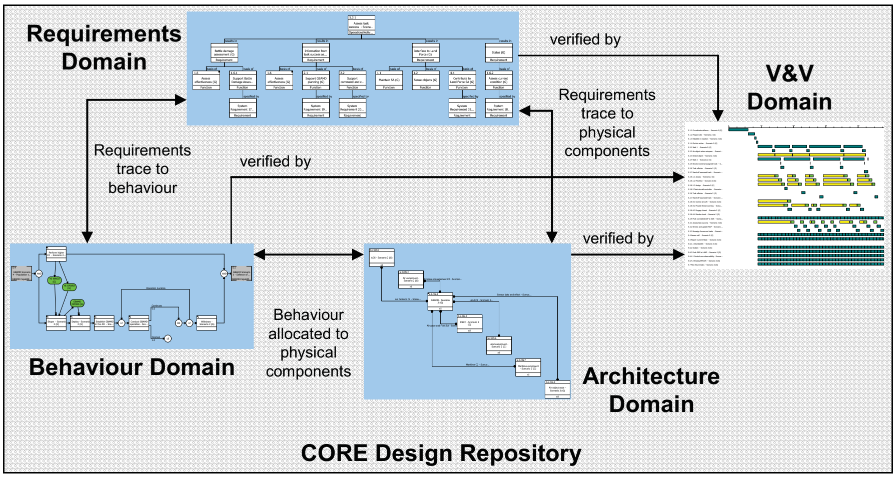

Figure 1. Vitech approach to MBSE redrawn from (Vitech 2009)

Benefits of MBSE. The INCOSE Model Based System Design Interest Group (Baker *et al* 2009) highlighted a number of benefits to both the customer and the supplier of the system in deriving specifications from a model:

- More effective translation of user needs into programme requirements. The customer is more likely to get what is needed.
- Early problem discovery leads to collaborative solutions between customer and supplier that can be incorporated more effectively earlier.
- Issues and trades are visible to support decision making.
- Greater supplier accountability results from inherent progress visibility.
- Availability of validated models for qualified components encourages reuse.

Baker et al summarise the supplier benefits applicable to deriving specifications from a model:

- Hierarchical decomposition of models supports visibility of information at its level of relevance and therefore its criticality to the design.
- Rigor of the models helps to avoid ambiguities, mistakes, and rework.
- Status of designs, processes and compliance is visible and traceable as a direct result of the model.
- Models provide linkage between hardware, software, and other design elements. This is important throughout the life cycle enabling system level interfacing errors to be identified early.
- Reuse benefits are similar to those for the customer.

WSAF for MBSE. WSAF unites the system definition, client and operational domains with the analytical domain, using an underlying architectural reference model that is supported by an application process. Where appropriate, this builds on the DAF (Defence 2009a), resulting in a definition of the analytical requirements for the scientific analysis of capability (Robinson & Graham 2010)**.**

This approach allows for more transparent application of analysis methods in the military space, thus linking the capability analysis to the military requirements and allowing for traceability of military requirements to the supporting scientific analysis in an auditable, rigorous and robust way.

Through WSAF application to scientific analysis it was established that, with minor modifications, its use could be extended to MBSE for capability development. Both applications require a knowledge model that can be queried to generate appropriate documentation. The WSAF, in its support of scientific analysis, conforms with the DAF and importantly is consistent with CDD guidance (DMO 2009) and fulfils the model requirements outlined by (Ogren 2000).

The WSAF architecture includes the following elements:

- **Knowledge Model (KM)** – Conceptual model (combination of architecture, logic and descriptions) of the capability of interest described from differing perspectives, or views. For example, and as described by the DAF (Defence 2009a), there are the Operational Views and System Views.
- **Reference Model (RM)** (aka meta-model) – This is the underlying description, based on EA theory, that identifies elements and their relationships in the system of interest and underpins the KM.
- **Process Model (PM)** – Describes how the KM can be developed and applied though the RM and is aligned to best practise such as the Guide to Understanding, Implementing and Delivering Experimentation (GUIDEx) (TTCP 2009).
- **Data access** – Supporting the access to the KM is a portal and a series of scripts that can be executed to partially auto-generate WSAF application documentation (such as the POCD and PFPS).

The WSAF employs CORE® (Vitech 2009) to realise the KM, RM, PM, and data access required for its application to capability development. CORE® provides a software environment that can encapsulate these components and support the activities required to develop operational needs and system requirements required for the POCD and PFPS.

Client perspective. The development of the WSAF for capability analysis was briefed to the LAND 19-7 client Defence Capability Development Group. Whilst previously the WSAF had been configured to support the prioritisation and planning of analysis tasks for Airforce projects, the proposal was to extend the WSAF in a new direction (MBSE) and for a new purpose (GBAMD). The client was aware of MBSE and its theoretical benefits, however, to best of his knowledge, there was no prior capability development 'template' to follow in applying the WSAF. The client had to balance the promised benefits against the need to invest substantial project development funds and staff effort (including from the project stakeholders) to develop the WSAF for the GBAMD application. The tangible success that had been achieved in the analysis domain and potential benefits that could be achieved were factors that lead the client to a desire to refocus collective efforts away from simply producing templated capability definition documents. This development of a rigorous capability for defining requirements led the client to the assessment that the MBSE approach was likely to be the most effective means to define the future GBAMD capability.

MBSE and the Capability Life-cycle. The MBSE methodology described here is employed to produce the CDD needed in the Requirements Phase of the capability life-cycle depicted in Figure 2 (Defence 2006, pp 5-6). These documents are prepared in accordance with existing Defence requirements (Defence 2009a). MBSE is used to enhance the rigour, logic and internal consistency of the CDD – not to change them. While, as a general principle, the use of MBSE may be extended to other phases in the capability life-cycle, to date it has been applied only to the Requirements Phase. Hence the discussion in this section of the paper is confined to the Requirements Phase. The future broader application of the MBSE technique is also briefly discussed in a subsequent section.

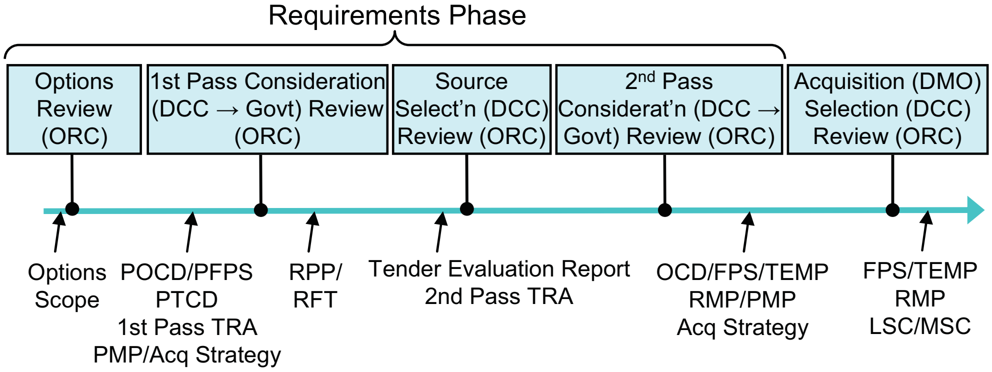

Figure 2. Requirements Phase events and supporting documentation redrawn from (Defence 2006)

MODEL CREDIBILITY

MBSE represents a logical, rigorous methodology for eliciting and structuring the information required in producing the capability definition documents. At its core is a model of the system of interest. Effort needs to be expended to ensure that the credibility[2] of the model is fit for the purpose of generating capability definition documentation. Two methods for enhancing the credibility of the model have been employed here:

- **Reference Model.** The RM facilitates the collection and communication of information collated in the KM. It describes logical linkages and relationships between the various elements of information to be recorded and maintained in the KM. This rigour enhances the process of populating the KM, and therefore increases model credibility.
- **Verification, Validation and Accreditation[3] (VV&A).** Borrowing the VV&A approach from the modelling and simulation domain and applying it to the development of the KM enhances its correctness and ensures that it is fit for purpose. The reader is referred to the Modeling and Simulation Coordination Office Recommended Practices Guide (US DOD M&S CO 2009) for further reading.

These two methods should ensure that the model is credible and fit for purpose. Notwithstanding this, documents generated from the model still have to undergo a document approval process.

Reference model. The WSAF RM developed for MBSE is depicted in Figure 3. The RM employed for capability analysis has been extended to facilitate the MBSE process. As discussed above, the underpinning of the KM by the RM ensures that the process for populating the KM is rigours and robust thereby enhancing the credibility of the model.

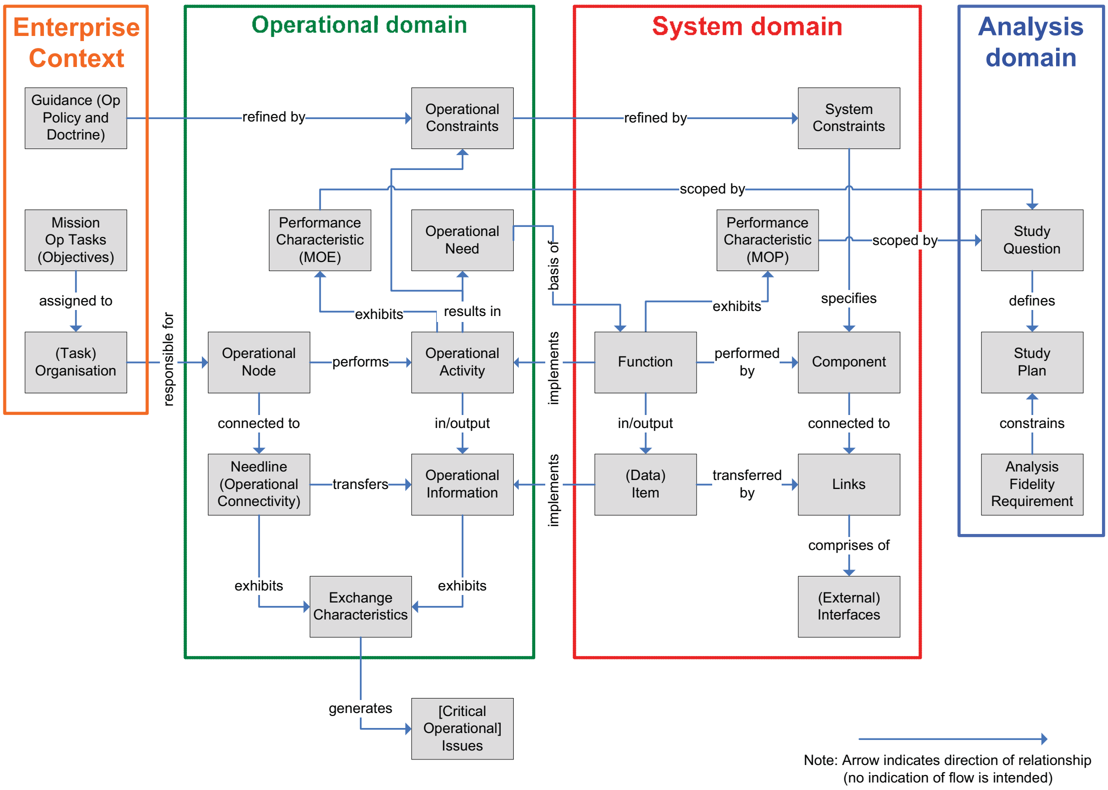

Figure 3: Simplified WSAF Reference Model

2. Credibility: The relevance that the user sees in a model and the confidence that the user has that a model or simulation can serve his purpose (US DOD M&S CO 2009).
3. Accreditation: The official certification that a model, simulation, or federation of models and simulations and its associated data are acceptable for use for a specific purpose. (US DOD M&S CO 2009)

As illustrated in Figure 3 there are four domains of interest that represent the stakeholder community; strategist, capability manager (operational domain), system engineer and analyst. This representation communicates to the stakeholders how the information they provide should be organised and describes the context and inter-relationships of that information, thereby enhancing its credibility.

The four Domains used in MBSE and on which the WSAF KM structure is based are explained below:

- **Strategic Domain.** In the Strategic Domain the missions and tasks which will be performed by the capability in question are identified. An analysis of national strategic guidance regarding the principal tasks of the ADF and the relevant strategic contexts is performed to identify the broad capability missions. The missions are analysed in turn within the context of strategic warfighting doctrine to decompose the tasks to be executed in accomplishing the broad missions.

- **Operational Domain.** In the Operational Domain, the tasks identified for each mission are analysed in the context of operational joint and single service doctrine to identify the operational activities to be executed in accomplishing the defined tasks. This analysis takes cognisance of the potential physical environments (e.g. terrain, climate, weather, atmospheric conditions etc). There is also a need to consider joint force and single service preparedness requirements.

- **System Domain.** In the System Domain the operational activities are analysed to decompose the functions required to enable execution of the operational activities. The functions are further analysed to develop requirements statements. The content of the System Domain will vary depending on whether the project is at the 'solution independent' or 'solution dependent' stage.

  – **Solution Independent Stage.** At the solution independent stage functions can not be allocated to physical system components. However, it is possible to identify candidate technologies that may be involved in the performance of the various functions. For instance candidate technologies for performing the Sense function may include electro-optic, radio frequency, acoustic or other forms of sensing.

  – **Solution Dependent Stage.** At the solution dependent stage, system components are identified and in producing a RFP or RFT, the requirements statements are further developed to include performance characteristics and qualification methods. The performance characteristics, where appropriate, are referenced to relevant military or commercial standards and specifications, while the qualification methods are expanded to identify the relevant methods of verification.

- **Analysis Domain.** The purpose of the Analysis Domain is to support the structuring of analytical studies to support capability development. For further reading see (Robinson & Graham 2010).

Model Verification, Validation and Accreditation (VV&A). As noted in the description of System Domain activities above, operational activities are analysed to decompose the functions required to enable their execution (or 'function implements operational activity' in Figure 3). While this is carried out as a workshop activity and is in common with current practice, the MBSE approach introduces two innovations. In the first instance the activity flow is executed in COREsim™ to enable verification of the inherent logic and defined activities. Secondly, the operational activities are validated through wargaming. Both of these steps rely on the development of operational scenarios that are representative of the capability missions. In addition, one or more vignettes are developed as instantiations of each scenario.

With verification and validation evidence presented, the credibility of the activity model can established and accreditation conferred, *i.e.* whether the model is credible and fit for purpose.

MBSE FOR LAND 19-7

The DCP 2009 (Defence 2009b) gives the following description of Project LAND 19-7: 'Under LAND 19 this phase is intended to enhance or replace the existing Ground Based Air Defence (GBAD) system (RBS 70 based). It will include technologies and weapon systems that are also capable of Countering Rockets, Artillery and Mortars (CRAM).'

WSAF Application to LAND 19-7. As shown in Figure 2, leading up to 1st pass consideration, the LAND 19-7 Integrated Project Team (IPT) is developing the Preliminary Capability Development Document (PCDD) set. This work commenced in May 2009 with the development of the POCD and PFPS utilising MBSE in the form of the WSAF. The WSAF process employed to produce the PCDD set is outlined in Figure 4 and is described in the following sections.

Figure 4. WSAF for CDD support process model block diagram

Identify Missions. As shown in Table 1 four prioritised missions were developed for the GBAMD capability based on the ADF tasks and strategic priorities outlined in the Defence White Paper (Defence 2009c). The missions were constructed to emphasise employment of the future GBAMD system as an integrated part of a joint or coalition force Integrated Air and Missile Defence System (IAMDS). The proposed missions were developed within the IPT and verified by the stakeholder community.

Table 1. GBAMD capability missions

Mission		Description	Priority
1	Force Protection / Defensive counter-air	Provide force protection against the current and future air threat.	Primary
2	Offensive counter-air	Provide offensive counter-air to shape and influence enemy air capabilities.	Primary
3	Airspace management	Support Joint airspace management functions over the Land battle space.	Secondary
4	Situational awareness	Contribute to situational awareness of airspace over the Land battle space and provide Joint Land Force with airspace situational awareness.	Secondary

Build illustrative scenarios. At the project inception there were no approved ADF scenarios, so the LAND 19-7 Desk Officer developed a series of scenarios (verified by the stakeholder community) to cover the identified missions shown in Table 1:

1. Defence of Australia. Conduct Independent warfighting operation on home territory.

2. Offshore Coalition Warfighting. Contributing to a coalition conventional warfighting operation offshore.

3. Stability Operations. Lead stability and indigenous capacity building operation in regional island state.

4. Population Support. Conduct independent population support operation.

These scenarios were mapped to the four missions and were based on the Adaptive Campaigning doctrine (Australian Army, 2009) and on the White Paper 2009 requirement that the ADF must have the capacity to act independently, lead military coalitions and make tailored contributions (Defence 2009c).

Build activity flows. The construction of the activity flows and associated DAF views addressed all scenarios and missions. Application of the WSAF is illustrated using Scenario 2, which is conducted in four phases:

1. Preparation and project of land force.
2. Provide GBAMD to amphibious lodgement (used here to illustrate the WSAF method).
3. Conduct conventional warfighting operation.
4. Withdrawal.

Figure 5 shows the DAF development process (Defence 2009a). The WSAF KM provides the repository to capture the required architectural definitions for the generation of DAF views. The WSAF RM provides the structure within the KM that ensures the correctness of the classification of information and relationships between classifications.

An iterative process of SME and stakeholder engagement was used to populate the KM. This enabled information to be captured that was appropriate to the stakeholder at a level of detail or decomposition as required. This also provided the first level of knowledge validation.

Model validation was further enhanced through the use of COREsim™. COREsim executes the KM behavioural model to provide a timeline output. This facility was used to discover errors in the activity model, such as errors in logical sequencing. It is particularly useful where activities are decomposed to the point where error detection by inspection becomes difficult.

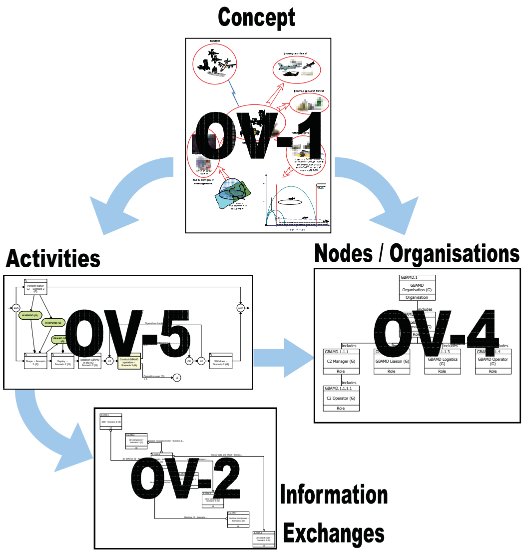

Figure 5. Partial DAF development process employed in the WSAF

Develop Operational Needs. A wargame was used to develop the operational needs and to provide additional validation for the WSAF KM. This served to identify errors and clarify the purpose and content of the activities and helped refine the GBAMD system interface requirements.

The wargame was conducted as a map based exercise (MAPEX) and involved SMEs as RED and BLUE role-players. A series of focused questions relating to the execution of GBAMD activities and the accomplishment of GBAMD tasks were used to identify operational needs. Plenary discussions refined the list of operational needs during and post the exercise. The solution independent operational requirements were derived from the operational needs at the conclusion of the wargame.

Although the major focus of the wargame was to identify and generate a GBAMD capability requirements set, an equally important concurrent activity was the progressive identification of issues, risks, MOEs and COIs and their capture within the WSAF KM.

Develop functional model. The system functional model was developed through workshops with the project team and SMEs. Functions were initially selected from a set of generic functions maintained in the WSAF KM (reused from previous projects) to fulfil the identified operational needs for LAND 19-7. In some cases additional or modified functions were required for the system to fulfil the LAND 19-7 operational needs. Where appropriate these new or modified functions were included in the generic set of functions in the WSAF KM for future reuse.

Develop system requirements and constraints. System requirements were developed directly from the functional model. Each function was specified by at least one requirement. Further to the functional requirement, non-functional requirements and constraints were developed that fulfilled the operational needs and constraints.

Produce document output. CORE® scripts were utilised to produce the required capability development documents directly from the WSAF KM. Figure 6 depicts the WSAF RM and how the knowledge captured within the WSAF KM relates to the sections of the POCD, and appropriate DAF views. The scripts query the WSAF KM and produce Rich Text Format (.rtf) documents with the correct content and structure (DMO 2004, DMO 2009b) that can easily be imported into applications such as Microsoft Word.

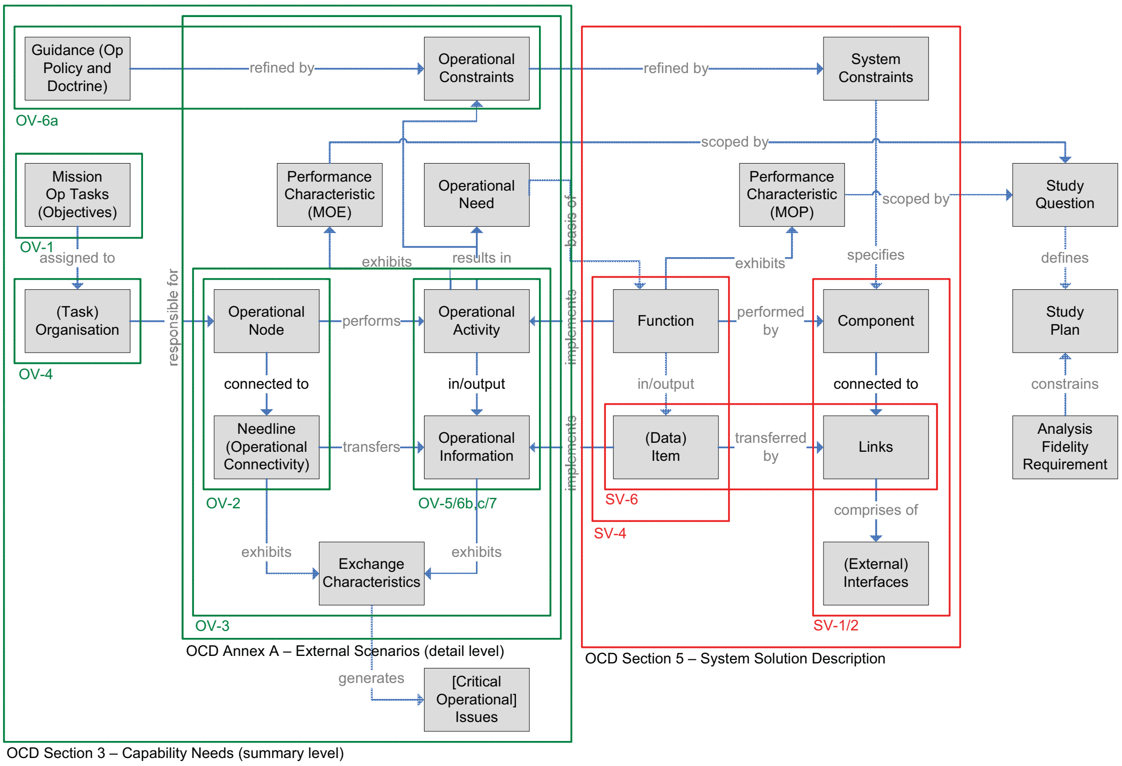

Figure 6. Relationships between WSAF data classes, DAF artefacts and OCD sections

Process example. The information captured within the WSAF KM is logically connected as defined by the WSAF RM depicted in Figure 3. Figure 7 provides an example of how a system requirement is derived through relationships specified in the WSAF RM following the process outlined above.

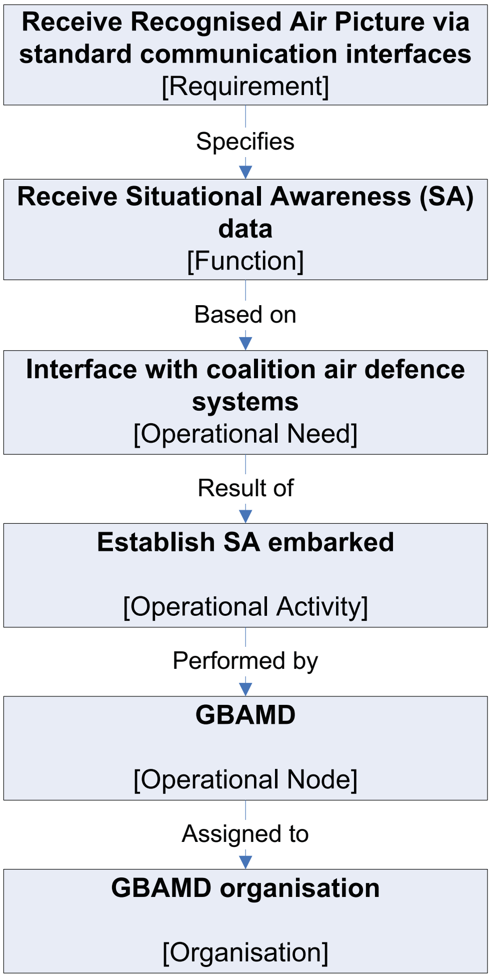

Figure 7. WSAF process example

SUMMARY

Outcomes of the LAND 19-7 Experience. The execution of the WSAF process for MBSE provided the LAND 19-7 stakeholders with the documentation that met the needs of the project at its current point in the capability lifecycle. Furthermore, the documentation produced fulfilled the requirements of the CDD guide (DMO 2009a), DIDs (DMO 2004, DMO 2009b) and DAF (Defence 2009a).

The knowledge captured thus far during this project resides in the WSAF KM and is readily available for future updates and iterations to support ongoing capability lifecycle requirements.

Conclusions. The aim of this paper is to demonstrate a MBSE methodology and highlight its benefits. The methodology was demonstrated through its application to the creation of the PCDD for LAND 19-7. As was shown, the MBSE approach is completely compatible with current mandated (document-centric) capability development processes and associated guidance. The benefits of this approach identified through the experience of using WSAF to generate the POCD and PFPS for LAND 19-7 are:

- Enhanced credibility of the end result through the verification, validation and accreditation of the knowledge model and the employment of the underpinning reference model;

- Greater stakeholder engagement through the development of the model and associated process leading to enhanced understanding between stakeholders;

- Traceability of decisions leading to greater understanding of final documentation;

- Efficient use of the WSAF KM through the re-use of relevant model elements from other projects;

- Standardisation of language through the reference model and a common knowledge leads to a common understanding of the system across stakeholders;

- It is simpler and more robust to iterate and improve model versions, rather than text based documentation, as new knowledge becomes available. This provides the basis for a more efficient method for capturing knowledge that easier to keep updated;

- The knowledge captured in the model can be read and explored in a number of formats (CORE® exports in documents or hyperlinked web-pages, in addition to the modelling and simulation views). This, combined with the DAF views, should reduce the learning time for new users;

- The knowledge model is primarily focused on diagrams, with supporting text to fully define the capability definition. As a generalisation, readers understand diagrams more effectively that textural description alone. The system architecture is best explained in pictures, and the DAF mandates this (Defence 2009a);

- The ability to focus on the detail, without invalidating the broad system definition, allows an efficient and effective development of the KM that bridges all levels of abstraction; and

- Transparency of the documentation generation leads to improved risk management in the production of the documentation.

These benefits have been realised in the programme to date; however there are two further benefits that are yet to occur due to the enduring nature of the KM:

- The early development and implementation of the WSAF KM has a higher upfront cost, however this will provide greater efficiency benefits downstream as the knowledge model evolves with the project; and

- The WSAF KM has been enhanced through the LAND 19-7 project, which will in turn improve the efficiency of the application of WSAF to the next project.

LAND 19-7 Client Assessment. The client was very satisfied with development of the LAND 19-7 WSAF model and the adoption of the MBSE methodology in generating the preliminary CDD. This approach produced a valuable project knowledge repository that will ensure continuity during future staff rotations and will allow the CDD suite to seamlessly evolve with the capability definition process. Given the rigour of the methods employed and the extensive stakeholder interaction, the client assessed the underpinnings of the preliminary CDD to be very sound. With such a strong foundation, the client felt confident about the success of the further development of these documents as the project progresses through requirements definition and beyond.

Recommendations. As seen from the foregoing, the employment of an MBSE approach in generating Capability Definition Documents (POCD and PFPS) has been demonstrated for project LAND 19-7. This success has encouraged the LAND 19-7 Project Team to consider extending the use of WSAF to the production of further key documents. Accordingly, in the lead up to first pass it is planned to produce the PTCD and Technical Risk Assessment (TRA) using the MBSE approach and the WSAF as the vehicle.

TCD development will grow out of the functional breakdown and the following existing WSAF elements: MOEs, risks, and issues. There is a need to review and improve the existing content of these WSAF elements, and their relationships, and to write a new CORE script to output the PTCD document. This work can be initiated at the solution independent stage and will be built upon as the project proceeds through the Capability Life Cycle (Defence 2006).

TRA development will grow out of the functional breakdown and the critical operating issues and the following existing WSAF elements; risks relating to particular technologies and issues. TRA development will be initiated at the solution-dependent stage (i.e. post-1st pass). There is a need to write a new CORE script to generate a document in compliance with the DSTO TRA template. It remains to be determined whether the entire TRA will be contained within CORE, or whether specific elements of the TRA document (e.g. tables and annexes) will be generated by CORE. The WSAF TRA module will be built upon over time as the project proceeds through the Capability Life Cycle.

An argument can be mounted to extend the WSAF approach to the solicitation stage and beyond. Specifically, the preliminary FPS can readily be developed into the full FPS that is incorporated into an RFP or RFT. Additionally the TCD can be developed into a Test and Evaluation Master Plan (TEMP) and, if logistics and maintenance requirements are added into the WSAF KM, it would be possible to produce the Statement of Work (SOW) and the Integrated Logistic Support Plan. Further the TRA may be grown into a Risk Management Plan. LAND 19-7 offers the opportunity to explore the utility of extending the MBSE approach in at least some of the directions outlined.

BIOGRAPHY

David Harvey. Dr David Harvey is a systems engineer with an interest in robotics and control. He holds a bachelor degree and a doctorate both in the field of mechatronics. His Ph.D. project involved the design and implementation of a robot capable of emulating insect plume tracking behaviour. He works for Aerospace Concepts, an engineering consulting company which specialises in the development of complex-system capabilities. He is currently involved in the development of the Whole-of-System Analytical Framework (WSAF) at the DSTO for the provision of cross-defence modelling, simulation, analysis and capability development activities.

Despina Tramoundanis. Despina Tramoundanis joined the Royal Australian Air Force (RAAF) in 1981 where she enjoyed a 20 year career as an Armaments Engineer. At various times during her RAAF career she worked as a design engineer, an organisational performance analyst, a Chief of the Air Force fellow, and a project manager for two weapons acquisition projects. Upon retiring from the RAAF, she joined the Australian Defence Science and Technology Organisation (DSTO) at the end of 2001 where she works within the weapons capability analysis area of Weapons Systems Division. She is currently the Science and Technology advisor for the Ground-Based Air and Missile Defence (GBAMD) project. She holds a BENG (Chem) from Monash University (1981), an MSc in Explosives Engineering from Cranfield University (UK) (1988), a Master of Defence Studies from the University of NSW Australian Defence Force Academy (ADFA) (1995) and a Master of Defence Operations Research from ADFA (2007).

Kevin Robinson. Kevin Robinson has been working in the field of guided weapons since 1992. After graduating from Cranfield University (UK) with an MSc in Electronic Systems Design (Control Systems), he joined the UK's Defence Research Agency (DRA) where he initially evaluated air-launched guided weapons, predominately the Advanced Short Range Air to Air Missile (ASRAAM), before becoming the technical lead and manager on a number of guided weapon support programmes. In 2000 he qualified as a Chartered Engineer with the Royal Aeronautical Society and in 2004 completed an MSc in Advanced Systems Engineering (Guided Weapons) with Loughborough University (UK). In 2005 he left what had become the UK's Defence Science and Technology Laboratory (Dstl) and joined the Australian Defence Science and Technology Organisation (DSTO). At DSTO he is the Science and Technology advisor for the Follow on Stand-Off Weapon (FOSOW) acquisition programme.

Captain Mat Jones. Captain Mat Jones is an Australian Army ground-based air defence officer with operational experience in Iraq and Afghanistan. He holds an Honours degree in Physics and a Masters of Management degree in Defence Capability Development and Acquisition, both from the University of NSW. Captain Jones is currently the Staff Officer Air Defence within Capability Development Group (CDG) and is responsible for Project LAND 19 Phase 7.

Shaun Wilson. Shaun Wilson is the principal of aerospace and systems engineering house, Aerospace Concepts Pty Ltd. He is a practising systems engineer with broad industry experience spanning from aerospace and defence to mining and leisure sports. Shaun sits on a range of company boards and professional society committees. He is a graduate of the Australian Defence Force Academy in Canberra and holds a BE degree in aerospace engineering from the Royal Melbourne Institute of Technology, an MSc in aerosystems engineering from the Royal Air Force College, Cranwell in the UK and other tertiary technical and management qualifications. Shaun is a published author in a number of technical fields including network-centric warfare and space flight safety analysis.

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