A Roadmap For Simulation-Based Acquisition

Paul Pearce MIEAust CPEng, Systems Engineer
Deep Blue Tech Pty Ltd, Adelaide, South Australia
paul.pearce@deepbluetech.com.au

Abstract. To combat the growing complexity of systems integration, it is anticipated that systems will be increasingly created and integrated in a virtual environment. In this environment, capabilities can be tested, evaluated and adjusted prior to a decision being taken to advance the system to the next stage of its life-cycle. This approach reduces risk and provides opportunities to make early corrections in order to meet the requirements defined by the customer. This paper will explain how Deep Blue Tech has responded to trends in simulation-based evaluation and will outline how this approach is applied to the development process for a complete submarine system. The planned evolution of an integrated simulation architecture from a virtual concept submarine to a training platform is described. Conclusions from the work completed to date and the key lessons learned are also described.

1. INTRODUCTION

The practice of systems engineering is dependent upon test and evaluation (T&E) activities to provide information for design decisions at all stages of the system lifecycle.

In the acquisition of Australian defence capabilities T&E is traditionally conducted during and after the integration and construction of systems, and rarely before or during the design phase. Insufficient T&E effort during the system development phase can expose the project to design issues that become more expensive to remedy the later they are identified. In recent decades, this problem has become increasingly relevant as defence systems continue to grow in complexity. This issue is further exacerbated by the increasing role of software in these systems and the greater utilisation of 'off-the-shelf' systems. The Australian Department of Defence has begun to address these challenges relating to T&E programs and has recently published the 'Defence Test & Evaluation Roadmap 2008' [1]. This document defines the role of T&E during all phases of the Systems Engineering development process including the earliest stages of the project lifecycle.

The design of a complete naval submarine system epitomises the issues surrounding systems complexity. Numerous systems, both bespoke and 'off-the-shelf', are tightly integrated and the role of software in these systems continues to increase. Therefore it is absolutely critical in this environment that the system be analysed and evaluated against user requirements and design criteria as early as possible in the design lifecycle.

Modelling and simulation (M&S) activities are commonly associated with preliminary studies during the needs phase. M&S studies should continue to support T&E activities during subsequent system design and acquisition phases of a project. Inadequate M&S during these phases, and hence insufficient T&E, can produce significant undesirable consequences as outlined previously. Demand for M&S capabilities appears to be increasing faster than industry can provide. Indeed, the Australian Defence Simulation Organisation (ADSO) observed in its 'Defence Simulation Roadmap 2006' [2] that "increased engagement of industry and academia will be required to develop the simulation capabilities envisaged by Defence".

This paper will outline how Deep Blue Tech Pty Ltd (DBT)[1] has responded to the observations above. In particular, this paper will describe the planned evolution of an integrated simulation architecture from a virtual concept submarine to a training system. Finally, conclusions will be drawn from the work completed to date and the key lessons learned will be described.

2. MODELLING & SIMULATION

Currently DBT is formulating submarine concept designs with a set of highly integrated tools which make it possible to facilitate rapid, high level evaluation of a particular submarine design. DBT currently conducts or plans to explore a broad range of submarine modelling, including:

- Operation of submarine in the wider maritime environment – war-gaming
- Submarine performance and properties on whole of submarine level;
- Whole submarine system integration, including crew
- Modelling of candidate subsystems;
- Comparison of different physical submarine configurations;
- Cost;
- Production processes;
- Logistics and support; and
- Human-Machine Interfaces.

---

[1] Deep Blue Tech Pty Ltd is a wholly owned subsidiary to ASC, and is based at ASC's submarine facility in Osborne, South Australia

Figure 1 illustrates the primary phases of a submarine capability lifecycle and key acquisition milestones [3]. The following paragraphs describe how M&S is applied during these phases.

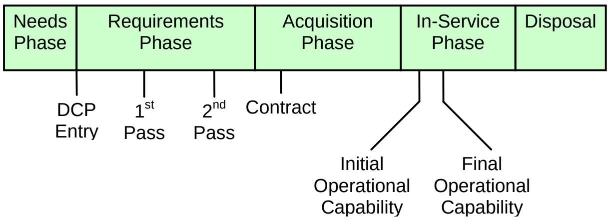

Figure 1 – Capability Lifecycle

During Needs and Requirements phases, M&S activities support the evaluation of the submarine design in terms of effectiveness, performance and cost. During this period M&S is used to support coarse-grained design decisions and trade studies focussed aspects of submarine that include submarine sizing, power demand, speed and endurance.

As the submarine system design is formulated during the Requirements phase, M&S activities support the naval architects and systems engineers in the design process. The focus of these activities is on the interactions between different submarine subsystems often including the crew. Topics of M&S studies during this phase include Human-Machine Interface (HMI) design, pipe-flow modelling, signatures, payload handling and damage modelling. As the design matures, the level of detail progressively increases whilst the scope of what is simulated decreases.

During the Acquisition phase, including submarine detail design and construction), M&S activities support the submarine production, integration and acceptance activities, and focus on issues such as production processes, operational task analysis and training needs analysis.

A range of simulation activities also support the development of a training concept, ranging from class room training to on-board training. M&S also plays a key role in preparing the first submarine crew for the First of Class tests and trials.

Traditionally, many submarine systems are analysed with specialised models and by different organisations, and are therefore often developed in isolation from each other, requiring significant and often manual effort to integrate these models together. It is anticipated that these systems will be increasingly created and developed in an integrated virtual environment. This approach should reduce project risk by providing opportunities to make early corrections in order to meet requirements defined by the customer environment where capabilities can be readily tested, evaluated and adjusted to support decision making.

DBT is actively working to make this 'whole-of-life', integrated virtual environment a reality, and consequently has begun developing a distributed submarine simulation tool called SUBSIM.

Before SUBSIM can be described however, it is important to introduce the distributed simulation architecture that currently forms the foundation of SUBSIM.

3. HLA AND VMSA

High Level Architecture (HLA) is a standardised framework for connecting multiple independent simulations called federates [4]. HLA has been developed over the last decade by the Defense Modelling and Simulation Office (DMSO) of the US Department of Defense, and has become widely adopted in many military and commercial fields. Within HLA, federates can publish and subscribe to information in HLA objects and interactions across a common run-time infrastructure (RTI). The RTI provides federation declaration, time and object management services in accordance with standard HLA policies [5].

Whilst DBT has adopted HLA for SUBSIM, the software has been designed to be independent of any particular distributed simulation technology. For example, a similar framework to HLA is Data Distribution Service (DDS), adopted by the Object Management Group [6]. DDS is a key standard used to implement open architectures for platform and combat management systems in military platforms [7]. Future implementations of SUBSIM could integrate with, or even migrate towards DDS.

The Virtual Maritime System Architecture (VMSA) was created by Defence Science and Technology Organisation (DSTO) to establish a standardised virtual maritime system framework for an HLA-based distributed simulation [8]. The VMSA has been adopted by both defence and industry to support simulation and experimentation with a number of key Australian naval capabilities, particularly the ANZAC Ships Combat Management System [9]. The DSTO VMSA product comprises a documentation set and a code framework that can execute on an HLA implementation such as the DMSO RTI-1.3NG [10].

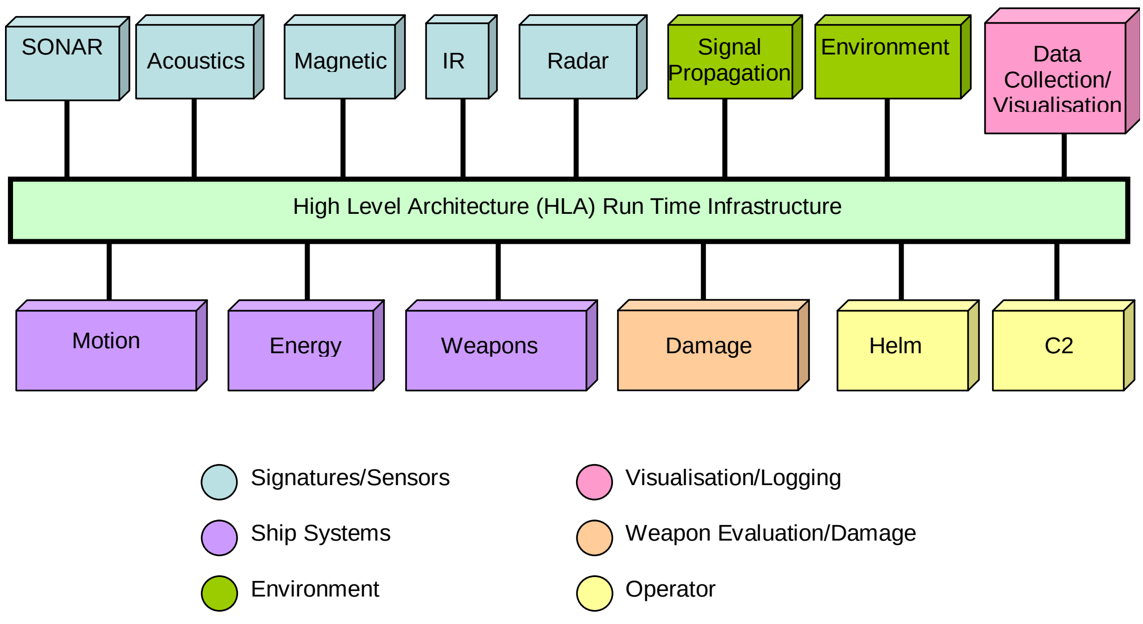

Figure 1: SUBSIM Overview

4. SUBSIM

The purpose of SUBSIM is to provide an integrated simulation environment and test-bed for a submarine design. It is planned that multiple sub-systems will be modelled dynamically as 'federates' in an integrated virtual submarine, with support for human-in-the-loop activities. A high-level overview of SUBSIM is illustrated in Figure 1. SUBSIM is designed to be operated in one of two simulation modes; 'analysis'; or 'real-time', as illustrated in Figure 2.

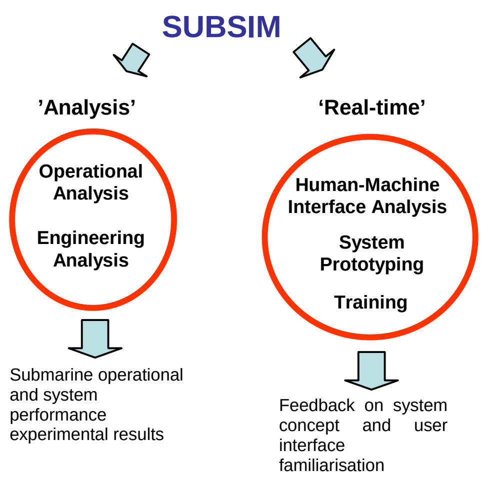

Figure 2: The Dual Roles of SUBSIM

From the perspective of the underlying VMSA software, the key difference between these modes is how often the simulation is time-stepped, and the period of each time-step. This deceptively simple change in parameters accommodates two very distinct types of requirements for the simulation. For example, where SUBSIM is used for operational and engineering analysis, the simulation is executed as fast the hardware will permit. Very little, or no graphics output is generated and the simulation hardware is devoted to intensive numerical computation. By contrast, when SUBSIM is operated in real-time, much greater emphasis is placed on graphical output, and use of peripherals, such as keyboards and joysticks.

It is important to ensure that SUBSIM can readily evolve throughout the submarine life-cycle as illustrated in Figure 1. Providing dual simulation modes represents one step towards improving the utility and longevity of this simulation.

Four types of input information are currently needed by SUBSIM to provide a meaningful simulation;

- Mission profiles (e.g. dimensioning scenarios);
- System model implementations (e.g. battery models);
- System model configurations (e.g. submarine variant/concept baselines); and
- HMI requirements (for consoles).

This information is provided through DBT research, studies and projects.

The output from SUBSIM is then used to verify submarine requirements thereby informing the requirements development process and helping to complete each concept design iteration as illustrated in Figure 3.

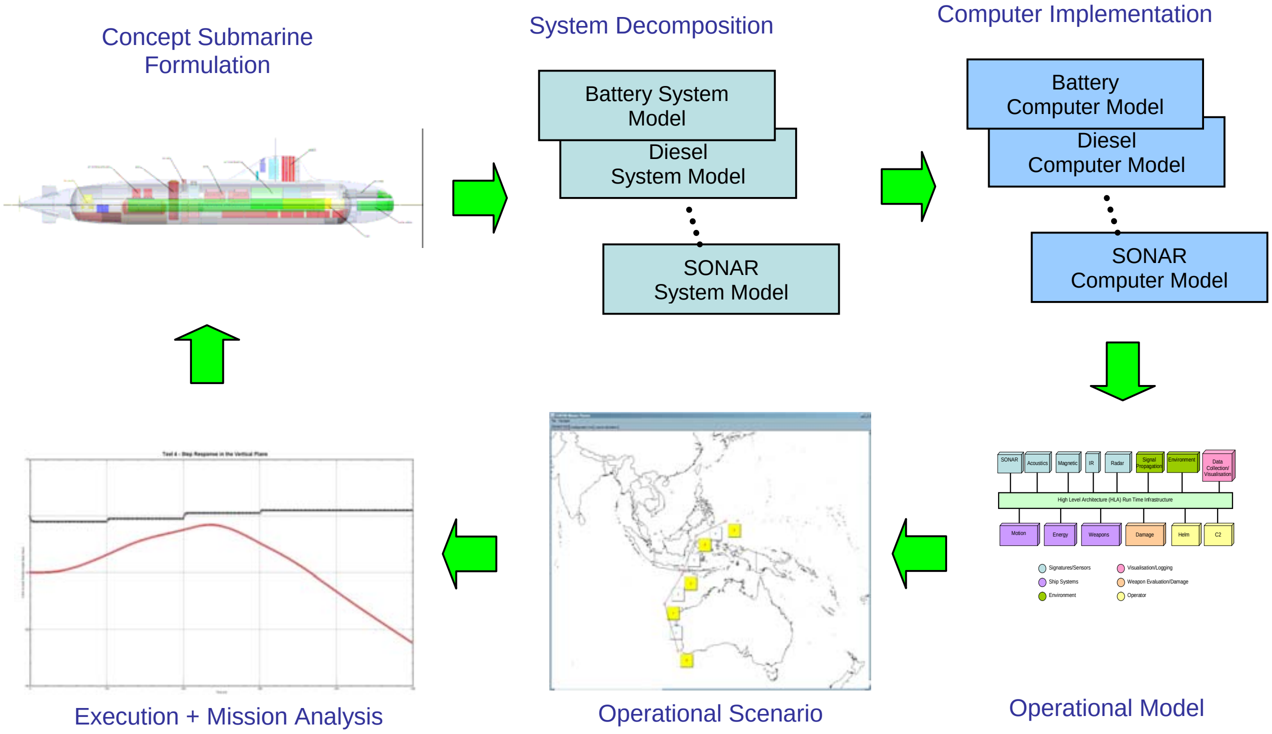

Figure 3: SUBSIM System Modelling Lifecycle

It is expected that a large number of submarine platform sub-system models will be allocated to federates, and that the underlying equations and theory will be modified regularly for the purposes of experimentation and the development of submarine design variants. Candidate submarine systems for modelling in SUBSIM were selected based on a review of the systems outlined in a standard military submarine system breakdown structure.

The list of candidate systems to be modelled includes:

- Diesel generators;
- Air-independent propulsion;
- Batteries;
- Main propulsion systems;
- Power conversion and distribution;
- Emergency ballast blowing;
- Steering & balance (including control surfaces & hydroplanes, bilge systems, ballast & diving systems, weight compensation, trim);
- Manoeuvring control;
- *Weapon storage, handling and discharge*;
- *Unmanned vehicle systems* (including launch & recovery);
- *Periscopes and optronic Sensors*;
- *Tactical radar, EW/ESM, SONAR*;
- *Combat, communications and control*; and
- *Navigation*.

The systems listed in italics indicate areas outside DBT core expertise, and are considered likely candidates for third party models that can be integrated within the SUBSIM architecture.

Currently, three core SUBSIM federates have been developed; Motion, Helm and Energy. These federates work together to provide basic manoeuvring and energy modelling as illustrated in Figure 4.

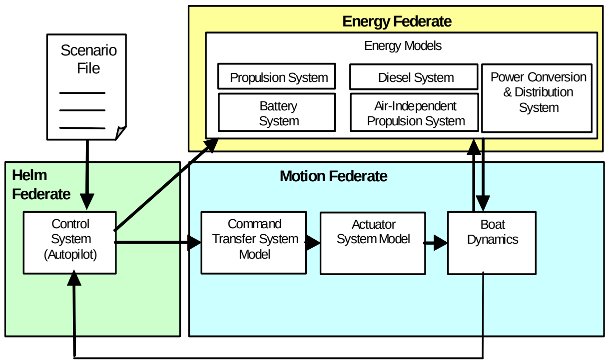

Figure 4: Relationship between Motion, Helm and Energy Federates

In addition, an environment federate is under development to provide bottom topography and environmental data corresponding to the simulated geographic location of the submarine.

The Motion Federate subscribes to control surface and shaft speed commands. This information is first processed and then updated submarine kinematics information is published to the VMSA federation. This is achieved internally by executing a series of models that pass control information through command transfer, propulsion, actuator and boat dynamics models. The boat dynamics model is the central component of Motion Federate and is implemented with a proprietary time domain solver for hydrodynamics motion equations. Hydrodynamic coefficients and system parameters from concept submarine designs are generated through computational fluid dynamics modelling.

The Helm Federate subscribes to submarine kinematics information and publishes control surface and shaft speed commands to the VMSA federation. Helm Federate provides a graphical user interface to allow the user to manoeuvre the submarine in real-time and observe its progress in a three dimensional space. Alternatively, Helm Federate can drive the submarine as an auto-pilot, receiving heading, depth and speed commands from a predefined scenario.

The Energy Federate contains models of the four main submarine electrical energy systems; batteries, distribution, generation and propulsion. Two power generation models are currently implemented in this federate; diesel generation and air-independent propulsion.

To assist future human-machine interface studies, SUBSIM will also provide simulation consoles to mimic the equivalent submarine consoles:

- Propulsion Control Console
- Diving & Safety Console
- Manoeuvring Console
- *Combat Control Consoles*

At this stage only the Manoeuvring Console has been implemented in Helm Federate. In the future, Combat Control Consoles could be provided to the simulation by an external party.

In later design phases it is intended to integrate SUBSIM with real submarine systems. The advantages of designing SUBSIM to achieve this objective include;

- allowing system software development activities (such as proof-of-concept/demonstrations) to occur during the concept design phase of the project, before hardware is available or even specified;
- providing for early human factors design;
- facilitating early crew training/exposure to concept design; and
- providing a platform to perform operational testing, and even jointly with other virtual platforms.

Where applicable, federates may be developed with an Interface Definition Language (IDL) description [11], to facilitate integration with other distributed system technologies such as DDS.

5. SUPPORTING TOOLS

A program, called Mission Planner, has been developed for mission analysis studies to provide the user of SUBSIM with the ability to easily specify and record a mission profile for a simulation scenario. With this program, a mission profile can then be automatically executed by SUBSIM from a generated command sequence. The operational concept is illustrated in Figure 5.

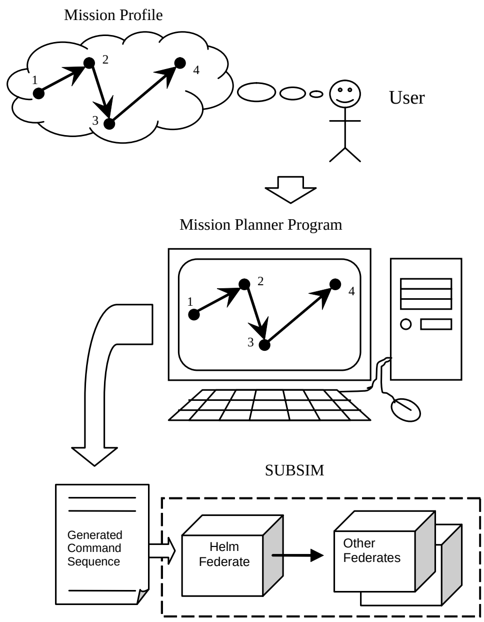

Figure 5: Mission Planner Concept of Operation

The Mission Planner also provides the user with the ability to load and save the configuration of all relevant parameters used by each federate. Importantly, a single file can be saved that captures the configuration of all system-based federates in SUBSIM. This file can then be formally configured as a document and base-lined for subsequent verification activities.

6. CHALLENGES AND OBSERVATIONS

The process of creating SUBSIM has presented many challenges to the development team, and considerable effort has been made to identify, resolve and learn from these issues as the project has progressed. From the beginning, this project established a rationale for developing a new virtual submarine simulation, and its role in DBT activities. This rationale was outlined in the introduction of this paper and the lifecycle diagram in Figure 3 serves to illustrate the role of SUBSIM in completing each design iteration.

A key emergent property of SUBSIM, when operated in ‘analysis’ mode, is its average simulation rate (defined as simulations per second) – this property is a product of many factors, including;

- the efficiency of the underlying HLA server software;
- the efficiency and fidelity of the system models;
- network latency; and
- computer processor speed.

At this stage, early evidence shows some benefit when distributing federates over a network. However, there exists a significant disparity between network latency and the speed of high-end computer processors being used. Consequently, a strategy for efficient use of networked computers is needed to minimise bottlenecks at both the federate and federation level. The current simulation hardware configuration is also being assessed against a list of performance requirements. These lessons will guide the procurement and configuration of future simulation computer services.

An appropriate level of fidelity for each model is also being maintained without unnecessarily sacrificing the simulation rate. To manage this issue, objectives for SUBSIM are regularly reviewed to ensure that models are not processing or generating information below the level of interest needed for purposes of the simulation.

The key role of SUBSIM for DBT at this point in time is to verify operational and system requirements. The challenge is to develop a virtual submarine that can reasonably approximate a real submarine system. Therefore the verification of SUBSIM is a critical task, and models within each federate must be subject to a documented suite of federate-specific tests. At the software level, unit-tests are being employed to improve the integrity of the software itself. The use of established proprietary models, where available, is preferred to the development of completely bespoke models. This flexibility is available to DBT as a consequence of building SUBSIM upon a distributed simulation architecture. It is expected that confidence in the SUBSIM results will be greatly improved by increasing the percentage of established proprietary models.

7. SUMMARY

The development of SUBSIM has provided DBT with the capacity to 'close the loop' on the iterative concept design cycle. A large number of submarine concept variants can be modelled in a single virtual environment, and the results can be used to verify their performance against the operational and system requirements.

A number of lessons can be drawn from the challenges presented above. Firstly, establishing the objectives of SUBSIM early facilitated a controlled iterative development process that evolved SUBSIM towards its objectives without becoming inefficient or unwieldy. The distributed structure of SUBSIM has permitted federates to be developed by the team in parallel, which has helped to compress the project schedule. Secondly, the adoption of standardised open-source simulation technologies and frameworks has accelerated the development process, whilst at the same time providing for future expansion by third parties.

As SUBSIM continues to mature, existing federates are updated and new federates are created. Many of the challenges discussed in this paper are managed carefully on a regular basis. An important future step will be to establish and demonstrate a practicable level of interoperability with parties external to DBT.

REFERENCES

1. Director-General Test & Evaluation (2008) "Defence Test & Evaluation Roadmap", *Defence Publishing Service, Department of Defence*, Canberra, pp. 12-19.
2. Director-General Simulation, Australian Defence Simulation Office (2006) "Defence Simulation Roadmap", *Defence Publishing Service, Department of Defence*, Canberra, pp 5.
3. Capability Development Group (2006), "Defence Capability Development Manual", *Defence Publishing Service, Department of Defence*, Canberra.
4. Dahmann, J.S. et al (1998) "The DOD High Level Architecture: An Update"
5. IEEE Standard 1516-2000 (2000) IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) — Framework and Rules
6. http://portals.omg.org/dds [Accessed 8/4/09]
7. http://www.rti.com/markets/military_aerospace.html [Accessed 8/4/09]
8. Canney, S. (2002) "Virtual Maritime System Architecture Description Document", *Defence Science & Technology Organisation*, Issue 2.00, July.
9. Bos, J. et al, (2003) "Combat Management System Integration into the Virtual Maritime System: A Case Study"
10. U.S. Defense Modeling and Simulation Office (2001) "RTI 1.3-Next Generation Programmer's Guide", *U.S. Department of Defense*, Version 4.
11. http://www.omg.org/gettingstarted/omg_idl.htm [Accessed 8/4/09]

COPYRIGHT