An Approach to Developing a Simulation-based Military Operations Analysis and Experimentation Capability

“Make a complex subject more understandable, and even wise men will thank you.”
- Ronnie Sheppard (Circa 1990)

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Abstract. The Boeing Australia Systems Analysis Laboratory (SAL) core capability is simulation-based military operations analysis and experimentation. Detailed and timely analysis is conducted in the SAL via a fusion of people, process and environment with a constructive simulation capability at its heart. The SAL has been charged in part to confront the many technical challenges that exist in the creation, management, development and application of simulation technologies in the military analysis and experimentation realm. The SAL simulation environment aims to provide a highly detailed, flexible, distributed simulation capability designed to bring the power of experimentation much closer to the operator with results that are more usable by the decision maker. This paper seeks to highlight the approach the SAL has taken to apply advanced distributed simulation, along with solid process to address the challenges inherent in the provision of a highly effective military analysis and experimentation environment.

1. INTRODUCTION
The Systems Analysis Laboratory (SAL) is a secure, research and development (R&D) facility built within the Boeing Australia Headquarters building in Brisbane, Australia. The SAL capability has been developed and its processes refined over the past three years to provide simulation-based military Operations Analysis (OA) to support external military and internal company applications. Specifically, SAL OA is focused on providing a deeper insight to support decision makers, and underpinning this focus is simulation.

Internally, the SAL is used to assess the feasibility and suitability of some of Boeing’s proposed technical solutions. This is particularly necessary to understand the system of systems implications for future capability, particularly on the ADF and other key customers. For example, whilst the Multi-mode Electronically Scanned Array (MESA) radar on the Wedgetail AEW&C¹ aircraft is becoming increasingly understood technically, many challenges remain in determining the most efficient and effective way of operating this capability. It is this type of ‘flow-on’ impact that the SAL is designed to quantify, assess and explore improved ways of applying such technologies.

Externally, the SAL conducts a very similar role, but mainly supports the ADF by providing deeper analytical insight into complex capability and concept-based problems. A core role lies in exploring the impact of various capabilities and technologies on an Australian deployed force under controlled mission conditions. Such mission conditions are derived using Boeing processes, but those processes are driven by, and rely on input from the ADF customer, the expert. It can be seen that customer - mainly operator / decision maker - input is critical in obtaining credible analytical outcomes. On the back of significant experience in supporting military decision makers in the United States (US), Japan and Australia, the Boeing Australia through the SAL is addressing the requirement for software to support structured simulation-based experimentation, which is currently not available off-the-shelf. The SAL has developed a framework to addresses difficulties inherent in distributed simulation, offers user friendly software tools to conduct experimentation, and embeds sound experimental process to provide access to the power of this approach by those without specialist technical knowledge in simulation-based experimentation.

2. THE SAL APPROACH TO CREATING A SIMULATION-BASED EXPERIMENTATION ENVIRONMENT
Applying distributed simulation is not technically difficult on many levels however, challenges are encountered in using a distributed simulation environment to conduct effective experiments for decision support. These challenges begin at the source of the requirement for usable experimentation, the decision maker. The most fundamental part of Operations Research, critical in providing a successful solution, is having a proper understanding of the problem.[1] Contrary to the ease of stating this, getting to the heart of a problem is a significant challenge under the best of conditions. In the complex world of military capability and emerging technologies, it is often difficult for decision criteria to be stated clearly; hence it is often difficult to design experiments to provide information to support

¹ Airborne Early Waming and Control (AEW&C) Wedgetail
them. Once a problem is defined, what is the most appropriate experimentation plan? What are the timeframes? What about data availability and quality? What are the levels of tolerance required in the results? What are the most useful measures of effectiveness? There is a lot to think of, and usually not a lot of time in which to do it. In particular, the ADF usually has tight timeframes for decision support and should expect an efficient process to support them in making complex, and often extremely expensive decisions. In addition to these issues, experience dictates that many distributed exercises are typically governed by technologists who are more concerned with distributed technologies than supporting decisions. In this regard it is encouraging to see the advancement of initiatives such as the Defence Experimentation Framework by the Military Systems Experimentation Branch (MSEB) of the Defence Science and Technology Organisation (DSTO), the Joint Synthetic Environment and the Army Experimental Environment (BASE)[4] will differ depending on the environment, with outcomes tailored to meet customer requirements. Processes must provide the customer with a complete analytical service, where customer presence and input are encouraged at every stage.

2.1 The Importance of Process
The SAL embarked on meeting the challenge of providing a rapid and useful simulation-based experimentation environment on several fronts. The requirement for solid and dependable process to underpin experimentation has been learned from the experience of many Boeing Phantom Works Teams and US Battle Laboratories the SAL operates with. The importance of adopting and refining a sound approach to problem definition and requirements elicitation was self-evident as a process starting point. In conjunction with the first major step in the process, it is also very important to identify the supported decision makers intent for the experimentation, and exactly what decisions must be made as a result of the analytical effort. A good parallel can be drawn to the ADFs modified appreciation process and mission analysis for operations staff to develop a plan that satisfies the commanders intent.

“Military experimentation is explicitly focused at investigating systems of systems and especially at identifying emergent properties.”[3] The SAL capability is applied via proven processes designed to deliver robust, timely and thorough analysis of complex problems in a system of systems environment, with outcomes tailored to meet customer requirements. Processes must provide the customer with a complete analytical service, where customer presence and input are encouraged at every stage.

2.1.1 SAL Process - Step 1: Problem Definition and Requirements Elicitation
One of most critical and difficult elements of providing useful analytical outcomes is successfully defining the problem and articulating the customers requirements in mutually understood terms. The SAL has many mechanisms at its disposal for such activities, and also a proven history of problem elicitation.

This stage of the process requires structured problem exploration, definition and bounding, and detailed requirements elicitation in a common vocabulary. Approaches and techniques used to date have included facilitated Grouputer-based sessions, direct interviews, questionnaires and several other approaches.

It is important for analysts to be well trained to conduct formal problem definition and requirements elicitation sessions in order to ensure a sound understanding of what is required. This in turn provides a sound experimental foundation for development and execution of an analytical strategy.

2.1.2 SAL Process - Step 2: Analytical Strategy Development
During the initial part of the SAL engagement process, customer’s decision criteria and other essential analytical foundations are quantified and weighted, based on customer knowledge and expertise, stated requirements and constraints. This part of the process provides those elements of essential information used in constructing Measures of Effectiveness (MOE). For military applications, many MOE are often encompassed by the term ‘Force Effectiveness’. Elements of Force Effectiveness, made up of groups of specific metrics extracted from the Boeing Analysis and Simulation Environment (BASE)[4] will differ depending on the analytical objective and what analytical elements go toward supporting customer decisions directly.

Various Measures of Effectiveness (MOE) will be selected in accordance with the study objectives, the mission environments, mission task verbs stated therein and the "what if" or other types of questions being explored. Experimental design is part of the second step in the broader SAL engagement process. Analytical strategies, often comprising simulation-based experiments, must always be based on the scientific method and sound statistical techniques applied to the customer’s requirements and derived MOE. For the more highly advanced approaches in analysis, the SAL has direct access to the ‘Best of Boeing’ experts in the US. This access is through organisations such as the Mathematics and Boeing Engineering Analysis Organisation, and the Boeing Applied Statistics Centre, both within the Boeing research and development centre, the Boeing Phantom Works.

In Australia, local agreements are also in place with senior faculty members of the Queensland University of Technology (QUT) and the University of Queensland (UQ). For example, QUT supported
analysis activities associated with the SALs F-111C GPS receiver and unguided bomb delivery study and, more recently, the populating of modelling databases. UQ has also supported studies in human factors engineering for F-111C. Boeing is a foundation member of the Distributed Computing CRC at UQ. Other agreements are in place with Griffith University, University of Southern Queensland (USQ), University of New South Wales (UNSW), Australian National University (ANU), Royal Melbourne Institute of Technology (RMIT), and CSIRO.

2.1.3 SAL Process - Step 3: Detailed Analysis

Step three involves the conduct of detailed analysis to generate the data that will comprise the MOE and form the foundation of the analysis required to meet requirements. For military applications, generally modelling and constructive simulation of appropriate military scenarios is used to more deeply explore a customer’s problem in a system of systems framework and identify and examine linked areas of interest. In this regard, entities within the SAL simulation environment are event driven, both internally (organic systems and situation) and externally (another entity’s systems or situation). Independent simulation events, such as third party entity detections, engagements and the crossing of phase lines- would in reality cause force elements to send communications in order to coordinate and control activities. BASE provides a constructive, event-driven environment that provides this greater level of realism. The SAL scenario generation process and OA staff experience allow either ADF scenarios to be used directly; constructed rapidly in conjunction with the SAL OA team; or for SAL staff to construct and tailor military scenarios optimised to meet special requirements, but without a constant customer presence.

2.1.4 SAL Process - Step 4: Tailored Output and Delivery

The SAL uses both open source and customer provided data to populate models and simulations. This data is stored in the SAL Information Repository outlined in the BASE capability description below. In addition to the foundation data used to populate SAL models and simulations, BASE allows a structured method of extracting the data comprising MOE. The BASE debrief tool allows an event timeline view into a DIS or HLA simulation stream for quick and easy identification of certain events over long timelines. Debrief can also feed information to 3D tactical, 2D tactical or 3D strategic visualisations of any simulation in a highly intuitive manner. This is well suited for the visual communication of complex analytical results and findings to allow reduced time to insight for the analyst and customer.

A second front designed to ease the burden of process is addressed through BASE’s reusable and expandable experimental platform. BASE hosts a suite of simulation applications consisting of COTS, Boeing Proprietary and US GOTS models. One of the goals of BASE is to automatically facilitate experimenters to use sound process and consistent experimental workflow, or if not use it, then to at least have considered it.

2.1.5 Underpinning Process - The Boeing Analysis and Simulation Environment (BASE)

The SAL approach to its software environment is one of selecting ‘best-of-breed’ COTS toolsets, rather than “black box” applications, and then integrating these toolsets to achieve a whole-of-simulation analysis environment. To avoid building new software each time for new tasks, the SAL has developed a simulation and analysis framework designed to be flexible to any COTS, GOTS or proprietary visualisation, simulation or analysis software packages. BASE fuses people, process and tools and in overview provides associate technologies that assist in simulation-based experimental design. It also provides a mechanism to control and store all background information and documentation associated with analytical projects. BASE also seeks to provide a framework to ease distributed simulation difficulties.

BASE Command. A Windows Explorer™ style overview application that helps structure associated experimentation directories, and stores the results of experimentation activities. BASE Command contains embedded experimental design and management workflows in a ‘wizard’ style format. It also allows the user to access any of the other BASE components.

Figure 1 – BASE Command screenshot.

BASE Debrief provides an advanced visual logger to allow users to record simulation data and visually analyse it.

$^2$ Integrating applications typically does not allow the level of configurability required for system of systems simulation.
BASE Analyst provides a common interface for creating, viewing, graphing, visualising and examining complex simulation metrics and measures of effectiveness. It also will assist in report generation.

BASE 3D is an advanced 3D visualisation environment that provides a highly realistic window into the simulation space and is particularly useful in ensuring the realism of the simulation environment by military domain experts.

BASE IR (Information Repository) is an instrumented database that stores country, platform, weapon and system data that underpins experimentation.

While BASE alone does not provide the simulations\(^3\) used in the generation of experimentation results data, it provides the framework and tools required for military operators to be able to conduct analysis without major intervention by engineers and scientists. In overview, BASE is designed to facilitate and to accelerate experimentation definition; provide the distributed simulation\(^4\) environment; visualisation of the battlespace\(^5\); rapid and meaningful analysis; visualisation of complex analysis data; distribution of study results and knowledge management for re-usability of analysis.

2.2 People - Skill Sets to Develop and Execute the Approach

Having mentioned the importance of process in the application of simulation-based experimentation, and also the SAL approach to providing a suitable software environment (BASE), there are several other important facets to the way in which Boeing have approached this problem. It was identified that the SAL would need a unique approach to team skill sets in order to successfully address the requirement to build an effective capability.

A multi-disciplinary team of experienced computer systems / software engineers and military operations analysts operates the SAL.

2.2.1 Modelling, Simulation and Visualisation Domain Expertise

The design and construction of such an environment requires advanced skills in the modelling and simulation domain. The SAL is staffed by some of the Boeing Company’s leading modelling, simulation, visualisation, knowledge management and integration technical experts. This expertise is reflected internally with Best of Boeing award nominations for analysis work on previous projects. SAL personnel are also representatives on national and international committees, within and external to Boeing. These technical personnel have enabled the SAL to build and continue to develop a world-class simulation-based experimentation capability.

2.2.2 Military Domain and Analysis Expertise

It has been found that for analytical staff to have military skills in addition to analytical skills has been highly beneficial in conducting military experimentation. Given the SAL focus on military operations analysis for decision support, the ability to construct credible military scenarios in which to conduct experimentation is an extremely important capability. This also allows closer and more useful communication with the defence customer, as there is a common vocabulary and understanding of roles already present.

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\(^3\) The simulations are made up by COTS, GOTS products

\(^4\) Through DIS and HLA

\(^5\) At the strategic, operational level through both 3D real world visualisation and tactical displays
Where appropriate, SAL simulated scenarios are based on ADF mission planning techniques such as the Joint Modified Appreciation Process (JMAP) and Intelligence Preparation of the Battlefield (IPB) and Electronic Combat Planning (ECP). Additionally, OA members possess core competencies in experimental design, data sampling strategies, statistical analysis, computer modelling and simulation, deriving and constructing Measures of Effectiveness (MOE) and data presentation.

A significant factor in the reasons for success in the approach the SAL has adopted is in the lessons it has learned internally and from its US cousins. One of the key lessons was the most appropriate mixture of tools.

3. CAPITALISING ON LESSONS LEARNED

OA is considered a science. One reason for this is because OA should have a “standard that demands that theories be open to examination, subject to peer review, and corroborated by experimentation.” [5] OA that uses models or simulations as tools should be viewed no differently. This statement asserts that where the practice of simulation-based OA issues forth a theory, the experimental results and findings leading to that theory should be reproducible within identified levels of error. Though not always the case, it is this level of robust OA that is normally required to support important decisions; although, it is recognised that less experimentally robust techniques such as war gaming have a very important role to play early in the problem refinement process.

It follows that to do robust experimentation well, the underlying simulation tools and their input data used to generate results and findings need to be of sufficient goodness and at the appropriate level. Goodness of tools goes to Validation, Verification and Accreditation (VV&A) issues, a subject which could, and has, formed the basis of many papers in itself. Addressing the many VV&A issues within the Australian Defence simulation arena, while tempting, is beyond the scope of this paper. Suffice to say, that in this context goodness [of a model or simulation] can be considered the level to which it achieves its stated aims or purpose [5].

Level in this context indicates its level of application. For example, it might be inappropriate to use a ‘man-in-the-loop’ campaign level simulation tool designed to train and exercise military staff to determine if a single tank is capable of providing effective fire support for a section attack under specific conditions. Lessons learned from the US experience by SAL staff have shown that in the early stages of embracing applied simulation technology in the field of analysis to support decision making, there is generally a high amount of enthusiasm and interest in the customer community about the technology.

Unfortunately, this usually does not come with a corresponding level of education; particularly regarding the limitations of simulation tools in analysis. Of note is the distinction between tools used for analysis to support decision making vice tools used for military skills training purposes. It also dictates a responsibility and a duty for those organisations that hold such experience to educate wherever possible.

In short, an integral part of providing a sound experimentation capability in this domain, in addition to correct process, is the correct selection of simulation tools and models with respect to goodness and level.

Many of the US experimentation centers tend toward many disparate tools that focus on highly specific areas. This in itself may not be a bad thing depending on the customer requirement. The lesson was learned when groups of these tools were being applied on broad problems beyond the level they were intended to deal with. Unfortunately, there were often cases when analysis was completed for the US DoD anyway with results that were sometimes dangerously misleading. [5] In the early stages of application of simulation technology in analysis, the US DoD customer did not know enough about the importance of tool selection. To address similar concerns in Australia, the SAL seeks to iteratively educate the customer and encourage expert scrutiny throughout the process. The SAL has also selected a coherent set of tools and does not apply them beyond their scope.

Many simulations have been built to satisfy a training purpose. For example, the Joint Theater Level Simulation (JTLS) is used extensively by the ADFWC in the training of commanders and their staffs. As a training tool, JTLS is very good and has many substantial benefits. The ADFWC has done some outstanding work in integration with in-service command support systems to enhance training value. As a tool it fulfills its intended purpose. US lessons indicate that simulation and war game tools designed for training almost exclusively make very poor analysis tools to support decision-making. There is often a tendency to bend the application of a training tool to analytical ends simply because it is available, and/or as a result of a lack of understanding of the limitations of the tool. Any simulation-based experimentation environment must carefully bound its domain and select the best tools to support their customer.

Many constructive simulation and modelling tools require skilled computer programmers (who are generally unskilled militarily) to construct entity behaviours that represent tactics and doctrine, and other major elements in experimentation. This has obvious consequences for the participation of
military operators in that they are generally removed from working with the tools directly. This may not necessarily be a bad thing either, but it was noted to be of greater benefit when military experts were able to use the tools and conduct the analysis with OA staff instead of remotely steering them. Heeding this lesson, the SAL software development team has striven to build the BASE framework to allow the military operations analysts and military operators to interact directly with all elements of the system as easily as possible.

3.1 Focus on a Domain

“Much abstract argument over model suitability is eliminated once its purpose is known – and not before.”[5] In light of the lessons learned through hard experience by SAL counterparts, the approach adopted here has been for Boeing to build a capability that allows it to deeply and robustly examine the impact of its products (particularly military systems) on the organisations of its customers. The value of this insight is self-evident. The domain or scope of capability the SAL has been geared to span the engagement level to the operational level of military analysis. Within this environment the goal was to better understand the impact on force effectiveness of various capabilities, force structures, operational concepts and technologies under Australian-like mission conditions. The level of required knowledge to be achieved from such studies is highly detailed, and this goes to refining the selection of the tools for the job.

As can be derived from the lessons learned outlined earlier, the simulations and models selected to support experimentation in the chosen domain constitute another critical path issue in delivering effective support to decision making. It is these tools, and importantly the data that populate them that largely determine the goodness of results. While another tempting opportunity for raising a contentious issue in data provision and other data related matters beckons, again scope precludes it. Suffice to say that a concerted data provision and standardisation effort on the part of the Australian Defence Organisation is required to facilitate more useful and unbiased experimentation that may be carried out in Industry and DSTO.

4. CONCLUSION

In overview, Boeing Australia has commissioned the SAL to embrace emerging simulation technologies as they apply to military analysis and experimentation. Currently this benefits Boeing internally by gaining a much greater understanding of the impacts of its products. From this, Boeing can identify strengths and weaknesses of solutions and position itself to provide the best possible technical solutions in terms of how they affect the wider system of systems environment in Australian Defence.

The ongoing challenge is to continue to refine and develop this highly detailed system of systems analysis capability. Specifically, the capability must continue to allow the examination of complex military issues such as the likely impact of the introduction of new capabilities, force structures, operational concepts and technologies. By leveraging significant experience from sister facilities in the US and capitalising on their lessons learned, the SAL has developed an internationally recognised experimentation capability. It has done this by selecting the best mix of skill sets and experiences; maximising the effectiveness of software and computer power in BASE in order to ease the complexity of distributed simulation-based experimentation for use by military operators; deriving and refining the most effective processes to support decision makers through robust experimentation; and constructing a facility designed to provide the best possible environment to allow complex decision support.

It is recognised that many elements of defence industry are doing leading edge work in the simulation arena. All of which represents a significant investment in the services available to the Australian Defence Organisation. The Australian Defence Organisation has the opportunity to capitalize on this significant investment and developed capability. It is now up to Defence to further engage and partner with industry to ensure its continued development and beneficial application.

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