Systems Integration Sandpit for Entrenching Innovative Systems Engineering Practice

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Abstract. This paper presents the Systems Integration Sandpit (SIS) established by the Defence Science and Technology Organisation and University of South Australia. The paper commences by describing the first two stages of the SIS development and early achievements against the facility's primary goals: exploring systems integration issues, the formation of systems engineering competencies by providing experiential learning, and research infrastructure to support the evaluation of emerging systems engineering practices, such as into Model-Based Systems Engineering (MBSE). From here, the paper discusses the ongoing research program for Stage Three that is focused on MBSE and systems engineering for evolving systems.

INTRODUCTION

A key challenge confronting Defence today is the management of acquisition programs for large-scale, complex systems that need to be tailored to national Defence requirements. A major contributor to this challenge is the complexity and rapidly changing nature of defence systems, particularly those related to sensors, combat and mission systems, weapons and countermeasures, avionics, and communications. In order to meet this challenge in the Australian context, it is necessary to build indigenous systems engineering and systems integration expertise and experience. To address this need, the University of South Australia and Defence Science Technology Organisation (DSTO) jointly established the Centre of Expertise in Systems Integration (CoESI) in 2006. One of the flagship projects has been a program named Microcosm, which has developed a Sandpit environment for the following three purposes: the investigation systems integration issues (in particular for evolving systems), supporting the formation of systems engineering competencies by providing experiential learning, and the provision of research infrastructure to support innovation in systems engineering practice. The project has passed through its first and second stage of development (Mansell et al., 2008; Cook et al., 2009) and has been renamed the Systems Integration Sandpit (SIS).

It has been suggested by the INCOSE 2020 Vision (INCOSE, 2007B) that systems engineering should move from the traditional document-centric methods to model-centric in order to address more adequately the systems integration issues that arise in modern systems acquisition projects. One key to improving existing systems engineering practice is thought to lie with better knowledge management across the project development team and other stakeholders – so that knowledge generated in one system engineering activity is made available reliably to the other activities that require it. This will allow the interdependencies between project components to be effectively managed. The INCOSE MBSE Working Group has been working towards this goal, and we are developing the SIS environment within the context of the INCOSE 2020 vision for MBSE as stated in (Estefan, 2009). Our view is 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 paper describes the Stage Three development of the SIS that specifically targets the evaluation of MBSE in the Australian Defence context. This stage also includes research tasks to provide demonstrations and an intellectual backing to our eventual recommendations.

SYSTEMS INTEGRATION SANDPIT (SIS)

SIS – Predecessor Stages. The SIS predecessor stages consist of the Stage One and Stage Two developments, where the physical elements (humans, computers, unmanned vehicles, deployable sensors, and simulators) were used to establish an environment for the undertaking of system integration research and education, adopting the concept of systems integration in-the-small as a precursor to systems integration in-the-large. Numerous lessons learned were captured that demonstrated this concept (Relf et al., 2009). Both of the SIS Stage One and Stage Two implementations used an operational scenario that was formulated by our defence customers and articulated using appropriate operational views (Do et al., 2009a). It consists of two unmanned ground vehicles (Pioneer 3DX robots), and two fixed global external sensors (a camera and SICK LMS 291 laser sensors). Each robot has a sensor suite, which consists of laser, ultrasonic, compass, odometry and vision sensors to perform specific tasks within the given scenario. Stage One and Stage Two were successfully implemented and delivered to key stakeholders, including demonstrations for the Minister for Defence Personnel, Materiel and Science, the DSTO Chief Defence Scientist and the DSTO Chief Systems Integration Officer (DSTO, 2009a; 2009b).

SIS – Stage Three. The goal of the SIS Stage Three is to develop compelling information regarding the utility of a true MBSE approach to systems integration projects. Stage Three focuses on: 1) developing the real and simulated components of the SIS to the stage that the environment will support the construction of complex scenarios for gaming and studying the range of issues that are encountered in real system development; and 2) using the Stage Three development to produce comparative documentation illustrating the differences between model based and document based systems engineering.

Stage Three upgrades the existing SIS Stage Two system, by evolving and enhancing the robot control and detection capabilities. This work is analogous to typical system upgrades of existing systems. As such, it provides a good case study for investigating issues related to systems engineering of evolutionary systems, against which to develop MBSE methods. Furthermore, the use of the interacting real and simulated models developed during Stage 2, provides the ability to generate much more complex and therefore more engaging demonstrations and provides a stronger physical base for our teaching scenarios.

In order to achieve the above, the SIS Stage Three project pursued three concurrent themes: Systems Engineering of Evolutionary Systems, Model and Model-Based Systems Engineering and Data-Centric Architectures for Systems Integration. Firstly, the systems Engineering of Evolutionary Systems theme consists of improving the existing robot controls systems, obstacle avoidance, path planning and self localization packages to allow for the recognition of simulated components as well as the real components using a formal MBSE approach. At the same time this work package included the development of a more complex perimeter patrol operational scenario, rather than the simple detect and track use case as in Stages One and Two. The perimeter patrol scenario involves programmed movement of one robot around the perimeter of the SIS physical environment, the ability to detect and identify multiple “intruders” and to track an unidentified intruder.

In addition to investigating the appropriate systems engineering process for evolutionary systems, technology adaptation and the systems integration issues associated with this were investigated. As a result, Stage Three implementation has included a feasibility study for the incorporation of an unmanned aerial vehicle (UAV) capability into the SIS environment. This enhances the existing SIS capability to investigate issues related to systems engineering processes for autonomous systems, interoperability between ground vehicles (UGVs) and UAVs, and further provide the option of increasing the complexity of operational scenarios to explore the essential aspects of systems integration of complex systems and system of systems.

The second component of the Stage Three project, the Model and Model-Based Systems Engineering work package, focuses on updating the SIS Stage Two Ground Station to manage the simulated components as well as the real components and to manage the new perimeter patrol operational scenario. The work includes developing models for the robots and the Ultra-Wide Band (UWB) system used as a surrogate GPS system by the SIS environment. The Ground Station is also undergoing modification to track and integrate the simulated robots with the real ones and to use the simulated UWB data as the global positioning reference for these robots. The realization of the scope of this work involves the evaluation and selection of appropriate models for the UWB system and their extension to incorporate them into the SIS environment. In order to support the new operational scenario and the need to develop complex teaching scenarios, additional models have been included for the positioning system, namely a transmitter model, a receiver model and a propagation model. The latter model is a statistical model used to analyse the physical properties of wave propagation from the transmitters to the receivers through the cluttered SIS environment to provide a simulation of these sensors to work with the simulated robots (Fontana et al., 2002; Ghassemzadeh and Tarokh, 2008). This model was also used to enhance the understanding of the MBSE approach and provided crucial simulated physical information for complex scenario development for research and teaching.

Finally, the Data-Centric Architecture for Systems Integration theme is a very important component of the SIS Stage Three work project. This activity takes the form of a feasibility study and an prototype implementation of a system-wide middle ware product, RTI-DDS. This product is already in service with the US and UK military, and provides a very good example of the need to understand how new technology should/can be introduced into existing large deployed systems. Thus it was seen to serve two purposes within this stage of SIS development – potentially providing a robust middleware layer for connecting the system components together, while at the same time serving as an excellent example of the type of issue facing ADF acquisition programs.

Model-Based Systems Engineering (MBSE). Defence acquisition programs usually have many of the following issues that lead to problems in system realization and integration. These include system of systems issues related to the need to integrate numerous systems developed for different purposes (Norman and Kuras, 2006), evolution of requirements and functions during system development, lack of knowledge of system interactions across the project team, integration of new equipment or capabilities into existing systems and the need to take account of the role of people in the functioning of the systems. All of these issues derive from the dynamic nature of system of systems development, which means that the traditional approach of process oriented systems engineering, which assumes a relatively static development environment, is no longer adequate. This does not mean that the traditional approach and tools are no longer needed, but rather that they need to be augmented with tools that allow systems engineers to identify, understand and respond to the dynamic nature of modern system development and acquisition.

In response to this need INCOSE set up the MBSE Working Group, which has produced a series of reports documenting its work and findings, culminating most recently in the 2009 report (Estefan, 2009) and the workshop held at INCOSE Singapore in 2009. Our approach in using the SIS environment to investigate MBSE application to these issues has been fourfold:

1) To develop tailored systems engineering documentation for the SIS Stage Three development and for comparison with a MBSE approach.
2) To develop, and use in parallel, a SysML based approach, using an advanced commercially available tool and to compare the results and products from this with those from the traditional process.

3) To develop small executable models of some components to help in the selection of various hardware units as demonstrations of how this can be included in a systems engineering study. Development and testing of executable models opportunistically forces users to uncover, understand and resolve many issues relating to performance, interfaces, etc. that might otherwise not be recognized until much later in the development process if only paper based reviews and walk through are used. Even if the model is never actually constructed, the act of designing it can work in this way.
4) To develop an environment that includes both real and simulated components in which both can be operational within a selected use case, with the real components stimulating the simulated ones, and vice versa. This allows the exploration of systems that mimic hardware and software in the loop testing systems, and also allows us to create much more complex, and therefore useful, scenarios for teaching and research than would be possible using just real components alone. At the same time, the use of real components ensures that we can include elements such as stability, friction, power degradation, signal attenuation, etc in realistic ways.

Development plans for the SIS environment beyond the SIS Stage Three include the incorporation of an agent based model of a human in the loop, designed to receive information and issue commands. This model is being developed for a separate application but will be adapted for use with SIS, thereby providing another example of the upgrading of systems in service that occurs in reality.

Systems Integration of Complex Military Systems. Since Australia usually procures military systems by selecting, tailoring and then integrating MOTS, COTS and developmental items, the integration of these systems is particularly challenging. The 2009 Australian Defence White Paper states:

"*As more technologically-advanced systems are introduced into the ADF (Australian Defence Force), there will be an increasing need for independent, deeply-informed science and technology support to reduce capability risk, and in integrating capabilities into the force structure…*".

The SIS provides a small scale test-bed where issues associated with the integration of MOTS, COTS and developing systems can be explored and understood. In particular, in the SIS Stage Three work, two feasibility studies have been conducted to investigate and develop capability in incorporating an unmanned aerial vehicle platform into an existing system, in the use of a data-centric framework to explore interoperability between UAVs and UGVS.

The first study focuses on use of a service oriented architecture (SOA) approach. An SOA that utilizes the existing web technology, infrastructure and open architecture to address interface issues between geographically disbursed systems based on the publish-subscription paradigm works well for a number of non-real-time commercial applications (eg for a web search where it is ok for the data to arrive a few 100 ms, even a second or two late). In real-time military systems, an SOA based system of this type will lead to system failures. As the result, DDS (data distribution service) has emerged as an industry standard, which was written by OMG in conjunction with Thales and other vendors to support a high-performance real-time data exchange, as well as QoS (Quality of Service) parameters such as availability, latency, priority and data ownership (OMG, 2007). Since the first release of the DDS Standards in June 2004, various vendors have been developing tools to realize its implementation and it has been successfully used in many large-scale defence projects such as the Aegis Weapon System developed by Lockheed Martin, the HiPer-D and the US Navy Open Architecture, etc. Furthermore, it has been reported that the US DoD has mandated DDS across the DoD (Pardo-Castellote, 2005).

The feasibility study was intended to review state-of-the-art development in DDS in the literatures (industry-based and academic literature) and investigate the benefits the DDS Standards has on systems integration of complex systems and system of systems. In addition, an evaluation and comparison of RTI-DDS implementation for the SIS System with our existing SOA architecture derived from Microsoft Robotic Development Studio, which was the architecture used for both Stage One and Two developments (Do et al., 2009e), was undertaken. The study provides an insight into the overarching questions of whether the data-centric architecture based on the DDS standard provides a means for enhancing the systems integration practice of complex systems. In doing this DDS features and constraints will be identified and the degree to which this approach facilitates system upgrades.

Systems Engineering Processes for an Evolving System. In order to maintain a capability edge throughout the life of systems and platforms, or to provide new capabilities to existing systems/platforms, it is necessary to upgrade, evolve and integrate new systems or sub-systems, and do so in a cost effective and timely manner. In Stage Two of SIS an intruder detection capability was developed, while Stage three work involved the introduction of new capabilities to patrol, identify and track intruders, a software upgrade to enhance the capability of the system to incorporate multiple simulated components working with the real components, and initial feasibility studies for a further software upgrade by introducing the DDS based SOA and the UAV autonomous platform into the real environment.

In general, the integration of new systems or sub-systems with legacy systems presents challenges which need to be addressed. These include:

- Sufficiency of pre-existing computing capacity to accommodate additional functionality
- Interface compatibility between the legacy system and the new sub-systems
- Electromagnetic compatibility
- Maintenance of system integrity and safety

These challenges can be better overcome by using a MBSE approach so the problems are identified earlier, and hence solutions can be determined before it becomes too difficult, costly or time consuming to solve. The SIS Stage Three development has encountered issues that fall into the above categories. These were captured as lesson learnt and will be used to inform good practice in evolutionary development and systems upgrade.

SUMMARY

This paper described the Systems Integration Sandpit (SIS) Stage Three development in collaboration with the Defence Systems Integration – Technical Advisory (DSI-TA). The SIS-Stage Three has been designed to: 1) explore systems integration issues related to evolutionary system development and system upgrades; 2) foster research and development in model-based systems engineering that moves toward executable model-centric systems engineering processes and process products; 3) investigate the feasibility of the data-centric architecture for systems integration of complex systems, and system of systems. In addition, the SIS-Stage Three artefacts, such as systems engineering process products, MBSE tools and the developed models, provide valuable resources for courseware development for systems engineering courses in our Master of Engineering and PhD programs.

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BIOGRAPHIES

Dr Quoc Do works at the Defence and Systems Institute (DASI), University of South Australia. He completed his BEng, MEng, and PhD at the University of South Australia in 2000, 2002 and 2006 respectively. His research interests are in the areas of mobile robotics (UAVs & UGVs), vision systems, systems engineering and systems integration research and education, and model-based systems engineering. He is the President of the Australian INCOSE Chapter, and also the Editor of the International Journal on Intelligent Defence Support Systems.

Prof Peter Campbell is Professor of Systems Modelling and Simulation with the Defence and Systems Institute (DASI) at the University of South Australia. He has a background in military modelling and simulation gained while working at Argonne National Laboratory in Chicago Illinois since 1986 and in environmental simulation gained from 15 years consulting to industry. He is currently working on the application of complex adaptive system simulation technology to large scale system of system integration projects.

Prof Stephen Cook is the Director of the Defence and Systems Institute at the University of South Australia. His career commenced with over ten years engineering experience in the telecommunications and aerospace industries after which he joined the Defence Science and Technology Organisation (DSTO) rising to Research Leader Military Information Networks. In 1997 he joined the university as the DSTO Professor of Systems Engineering and has led various defence research concentrations since. Dr Cook is a Past President of the Systems Engineering Society of Australia and his research interests include systems modelling, defence capability engineering, and identifying the theoretical basis for systems engineering.

Dr Ishan Samjeva Daniel Solomon obtained a BEng(Hons), BSc, MBA and PhD from the University of Adelaide, and a Graduate Certificate in Scientific Leadership from Melbourne University Private. Dr Solomon is the Head of Systems Integration Research at the Defence Systems Integration - Technical Advisory (DSI-TA) and he has worked on radar systems, sonar systems, and torpedo and torpedo defence systems. His research interests are in systems integration, real-time systems and processing, modelling and simulation, array signal processing and target tracking.