The Role of Synthetic Environments in C4ISR Modelling and Simulation

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Abstract

We present a case that Synthetic Environments (SEs) of varying degrees of complexity can address many of the difficult system issues of C4ISR system development that more traditional methods cannot. However it is recognised that complex SEs are relatively expensive compared to simpler modelling and simulation (M&S) approaches, and it is therefore important to select the most appropriate tool for each activity. We have adopted a three-phase approach to the role of modelling and simulation in complex system-of system development, with a key aspect being the use of Synthetic Environments to facilitate the study of system synergies and emergent properties. The paper is illustrated with the application of this approach to the problem of integration of an Armed Reconnaissance Helicopter asset into the broader Land C4ISR system.

1 Introduction

The objective of our work in C4ISR for the Land Force is to develop and evaluate new system concepts to effectively deliver the requisite knowledge[1] to the variety of decision makers to facilitate the making, execution and monitoring of decisions about military responses. The role of M&S in this work is to assist in the development of new concepts and then to allow rapid, cost effective but realistic testing of the resulting benefits and to provide feedback to the system designers for further development. Integral with such an iterative process is the development of various metrics such as measures of performance (MoPs) and measures of effectiveness (MoEs) with which to gauge improvements or otherwise at each step. These metrics must relate overall effectiveness of the C4ISR system-of-systems (SoS) in meeting military objectives to performance of individual components of the system under development.

An approach to the use of M&S in the development of C4ISR systems of systems is emerging (at least within elements of DSTO) which involves three phases, with different M&S techniques being appropriate for each. All three phases of this approach are characterised by the integrated teaming of scientific and military (user) expertise. This approach extends the Operational Analysis ‘Battlelab’ methodology [Bowley & Lovaszy, 1999] developed to support the Soldier as

[1] It is recognised that knowledge generation is a human cognitive function and that the system can only deliver the information and facilitate the generation of knowledge.

a Combat System study and underpin the Restructuring of the Army Trials, to include development and evaluation of new system concepts.

The first phase is the system architecture development and design. This phase itself entails a number of steps, the first being problem definition and refinement. This step involves human intensive techniques and is achieved through a combination of seminars, tactical exercises without troops (TEWTs) and wargames, following the ‘Battlelab’ process. The next step starts the system development and generally follows the operational architecture development process laid down in the US DoD endorsed C4ISR Architectural Framework [AWG, 1997], where system components and inter-connections are mapped out to meet the stated objectives of the system. The modelling required here is best achieved using a class of techniques that includes systems dynamics and a variety of event-driven systems modelling tools. With these models, process flows can be followed by inspection through the system and areas identified where functions could be improved and/or rationalised and where interconnections are required and of what quality. Such modelling is simple and inexpensive, and a variety of packages are available (eg Planimate, G2, CORE, RDD-100). The main drawback of such modelling is that the functions within the system cannot be represented with very high fidelity, particularly where human cognition and decision making are involved. This entire phase can be iterated a number of times, with an initial thrust of scoping the ‘lie of the land’ gradually shifting to filling in detail and identifying critical issues.

The second phase involves development of system synergies and emergent behaviour. This phase is the problem area that we are currently addressing with the SE approach. It will be discussed in more detail in this paper than the other two phases. SEs allow the functions within the system and in particular those involving human cognition and decision making, complex new technology and new operating procedures, to be represented to the degree of fidelity required for the specific investigation, by supporting integration into the SE of anything from simple numerical models to real equipment and humans, and even interfacing to external systems. SEs thus recreate all the intra-system interactions relevant to the component-level MoPs and SoS level MoEs, which may also depend on external system interactions. Appropriately designed SE experiments can therefore be used to elucidate the relationships between hierarchies of measures. Perhaps most importantly, the SE approach allows system emergent behaviour to be investigated by immersing human users and allowing them to develop and modify doctrine and tactics, techniques and procedures (TTP) to get the most out of the technology, while also allowing an interaction of these users with the system developers to modify the technology to suit evolving TTP. The use of SEs in this phase also supports the detailed data collection required to develop the constructive models of the new concepts needed for the investigations of the next phase.

The third phase of the system development is the assessment of the system performance over a wide range of possible scenarios. Since a large number of experiments are required to span the range of critical parameters, closed simulations such as CASTFOREM are used. In the previous case the SE has been used to facilitate development of system architectures and procedures optimised over a small set of scenarios, and these can now be transferred to CASTFOREM and evaluated over a much wider range of scenarios with the same MoEs and MoPs as with the SE. When, and if, system performance is found to be unacceptable for certain scenarios, the cycle of

M&S based development is iterated with modified architectures produced in phase 1 developed further in the phase 2 SE for the scenarios at question, and then re-assessed in the closed simulation analyses of phase 3.

This paper describes the three phase approach and illustrates this with reference to a case study involving the integration of an Armed Reconnaissance Helicopter (ARH) into the broader Land C4ISR system. The emphasis in this paper will be on the second phase, the role of Synthetic Environments.

2 Description of Case Study – Integration of an ARH into the Land C4ISR System

Identifying and developing the requirements for the integration of an armed reconnaissance helicopter (ARH) capability into the future Land C4ISR system has been a key focus in our application of synthetic environment based experimentation. This activity has also provided the primary vehicle for evolving the methodologies and techniques of how to effectively utilise synthetic environments to study complex systems of systems.

2.1 Background

The Australian Defence Organisation is currently in the process of acquiring a capability of two on-line squadrons of ARHs (Project Air 87). Their roles will include [ARH CED, 1999]: armed reconnaissance, precision firepower, escort of air-mobile forces, Command and Control (C2) support, and surveillance support. The first production helicopter is expected to be delivered in 2004, with the expectation that the first squadron will be fully operational by 2006. The new capability will replace the Vietnam War vintage Iroquois (air mobile and aerial fire support) and Kiowa (reconnaissance) helicopters.

Introduction of the ARH capability will result in a fundamental shift in the role of Australian Army Aviation from an essentially supporting role to operating as an integral part of a combined arms manoeuvre force within a Joint operation. Key to this integration is the role of the ARH as part of the C4ISR system. The ARH's reconnaissance attributes are expected to significantly contribute to an integrated Land Intelligence, Surveillance and Reconnaissance (ISR) capability [DEFCOP,1997] and the attack potential will have major impact on the requirements of the tactical C2 system. This shift to an air manoeuvre paradigm will require development of new doctrine (including TTPs) for both the ARH and the wider Land Force in order to maximise the impact of the new ARH capability within the battlespace.

Much of the required understanding will be acquired from overseas experience, tactics and doctrine. However, many of the lessons from overseas do not directly translate to the generally far smaller Australian forces. In addition, most of the overseas doctrine is not optimally suited to lower levels of conflict with complex mixtures of blue, red, and neutral forces as well as civilians. Therefore DSTO initiated a program of systems and operations analysis studies to assist the Australian Army in developing its concepts for using the ARH capability with a focus on the ARH in an air manoeuvre role.

2.2 ARH Study Goals

The overarching goal of the initial ARH studies was the development of a concept for how the ARH could be integrated into the C4ISR system. This was broken down into a number of subgoals:

- Identification of C2 and information flows for the ARH (addressed mostly in phase 1 for input into phases 2 and 3)
- Identification of the appropriate balance of voice and data based communications
- Development of requirements (mostly phase 2) for air and ground mission management systems providing the following functions
  - Information management
  - Mission planning and monitoring
  - Battlespace visualisation
- Development of new TTPs to maximise the potential offered by the shared Situation Awareness enabled by the technology of the mission management system (phase 2).
- Capture and refinement of resulting ARH TTPs (phase 2) to support operations analysis (phase 3).

3 Phase 1 - Architecture Development and Design

As outlined in the introduction, Phase 1 broadly follows the US DoD endorsed C4ISR Architectural framework approach to development of Operational, System and Technical level architectures[2]. Although the ARH study was carried out before this framework was available, many of the framework steps were completed nonetheless. We have since described [Seymour and Kirby, 1999] the ARH-C4ISR SoS operational architecture in terms of the three essential products of the framework. The system architecture has been based on the 'infospace' concept described elsewhere [Seymour *et al.*, 2000]. A technical architecture, [Kirby *et al*., 2000] and [Seymour *et al.*, 2000], using modern database replication methods and interfaces to applications via middleware, has been used to construct the concept demonstration systems that have been used in the SE experiments in Phase 2. We turn now to a description of the Phase 1 work for the ARH study.

3.1 Refinement of ARH Problem Space

The first iteration of this problem definition phase was achieved through a combination of inputs from military subject matter advisers (SMAs), and tactical exercises without troops (TEWTs), supported by wargames. Five groups of critical issues (CIs) were identified:

- C4ISR;
- Firepower;
- Doctrine & Tactics, Techniques and Procedures;
- Training & personnel;
- Readiness.

[2] This approach will not be discussed in detail in this paper, but may be consulted in [AWG, 1997].

The scope of the ARH study scenarios range from specific missions up to Task Force (TF) scale operations. Strategic guidance identified three broad scenario groups: medium to high intensity conflict in a Defence of Regional Interests (DRI) context, low intensity conflict or peace operations, and low to medium conflict in a Defeating Attacks against Australia (DAA) context. Most of the SE studies to date have focused on a mix of the DRI and DAA scenarios. Specific missions were identified through a DRI focused wargame.

Associated with the identification of critical issues is the determination of the measures of force effectiveness (MoFEs). In the broadest sense the overarching MoFE is the effectiveness of the task force within which the ARH is operating. This overarching MoFE has been broken up into a number of high level MoFEs:

- Mission success;
- Vulnerability;
- Fratricide / Collateral Damage;
- Availability of ARH capability

Each of these MoFEs has a number of contributing measures of effectives (MoEs) and performance (MoPs).

Our initial development of an operational architecture was achieved through a consultative process over several months in 1998 involving DSTO scientists, Army personnel from 1 Aviation Regiment and system developers. This involved identification of the functional elements involved in ARH tasking, mission planning and mission monitoring. The main nodes in this operational architecture were Task Force HQ, Aviation Battalion HQ and the ARH platforms, (with an additional node being the All Source Cell in a separate HQ).

A system design was evolved to satisfy this general operational architecture and a concept demonstrator subsequently built for further development in phase 2.

This approach to developing the operational architecture was something of a departure from previous C2 investigations, which had taken a process-oriented perspective, capturing large volumes of information to define and measure C2 processes. However, not only are the ARH C2 processes still evolving, but C2 staff have limited training and experience with those processes, and moreover many of the processes are scenario dependent. As a result earlier studies encountered significant difficulties in extracting broadly useful results. The large volume of data that needed to be analysed and the difficulty of modelling the, often experiment specific, processes tended to compound this problem.

More recently the operational architecture development approach used in 1998 has been carried out again with new staff in 1 Aviation Regiment, and extended to a more detailed functional decomposition of C2 within their headquarters [Rees et al, 2000]. This function-based description of C2 is capable of being mapped across a wide range of command levels and operational scenarios. As such it lends itself to modelling and prediction of changes to C2 structures and processes. It is intended to utilise this functional description as the basis of much of the next iteration of Phase 2.

Within the C4ISR Architectural Framework, the process we have described here is essentially a method for development of the key product OV-1, High Level Operational Concept Graphic.

4 Phase 2 – Development of System Synergies and Emergent Behaviour

The use of SEs to support capability development in Land Operations Division started in 1998 with simulated ARH missions integrated into a field exercise, and was aimed at raising issues and stakeholder awareness at the SoS level. These early experiments have been extensively reported [Grisogono et al., 1999] and [Grisogono, 1999]. One of their significant outcomes was the realisation that SEs could not only be used to trial and evaluate new concepts, but were in fact critical enablers for the development of new concepts. This role has been elaborated in [Grisogono and Teffera, 2000] and [Seymour and Grisogono, 2000], and essentially stems from two key aspects of SEs: their ability to recreate SoS complexity through actual interactions between representations of systems, and their ability to immerse humans from different backgrounds (Army, scientists, engineers, contractors, analysts and human factors specialists) in a shared problem space. This powerful combination focuses diverse expertise and strengths onto the very aspects of SoS design that are difficult: the interactions and synergies between components. Even the earliest and crudest attempts at SE experiments yielded a surprisingly rich harvest of lessons, issues and new concepts [Grisogono and Seymour, 1999]. The ARH SE experiments described here drew from these experiences and the use of SEs has now been integrated into the overall methodology described in this paper.

4.1 Design of the SE

The analyses of phase 1 had identified the key players and critical capability elements of the ARH. These factors then determined the elements required in the SE. Key roles (C2 staff in the various headquarters and the aircrews) require professional Army staff, immersed in the SE with sufficient fidelity to reproduce real world interactions. Therefore, the Situation Awareness system and the communications networks which support those interactions are of the highest priority. The simulated ARHs need to have representations of weapons, sensors (including electronic warfare self-protection), flight instruments and controls, to permit the aircrew to operate the ARH through all the aspects of a mission. However, the cockpits do not need to be high fidelity, since the focus is not on the actual physical layout, operability or dynamics of the platform.

The design of the SE also has to support the data extraction necessary for calculating the metrics listed in section 3.1 as essential to addressing the CI groups. Determining mission success, vulnerability and fratricide in the selected scenarios, requires the essential elements of the missions to be enacted in the SE, including interactions with appropriately behaving enemy and friendly entities. These are constructively simulated in ModSAF, and the ARH and target vulnerabilities, sensor detection and identification ranges and weapons engagement ranges have to be calibrated to real world data.

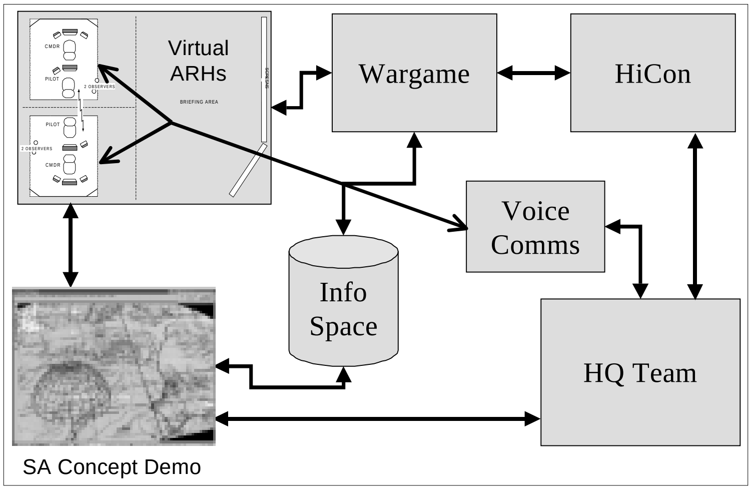
An aspect of SE exercises that offers significant advantages over live exercises is the ability to collect data which is difficult or impossible to access in the real world, and to process it in real time and provide 'live' metrics to exercise controllers while the action is being played out. An example here that assists in the optimisation and evaluation of the TTPs being employed, is the computing of realtime measures of risk factors and ‘window-of-opportunity’ factors to achieve the mission objectives. Since in the SE it is possible to know at every timestep exactly where every entity is and what it is doing, we can compute whenever an ARH is within line-of-sight and range of each threat, and can even do the same in parallel for militarily credible alternative locations of the threats, in order to compute a more statistically robust measure of the risk to which the ARH is being exposed. Similarly, the ‘window-of-opportunity’ is computed based on either the actual locations of the targets in the SE, or averaged over a set of plausible target locations, as the ARH executes its tactics in realtime.

Fratricide and collateral damage could be addressed in a similar way, provided the scenario employed is sufficiently complex that such issues would arise. In this regard, it is important that the information environment in which the aircrew and their commanders are operating is realistic, and does not present an over-optimistic picture of the level of situation awareness achievable. Entities that are detected by organic or off-board sensors must be reported with no more detail than the real world situation would provide, and must not take advantage of the global view that SE controllers can access. Decision-makers then need to judge whether entities are enemy, friendly or neutral, and apply the appropriate rules of engagement, which are part of the TTPs. Since there is always some uncertainty and incompleteness in the situation picture, this allows the possibility of fratricide and collateral damage to occur in the same way as in the real world.

Other issues such as the availability of the ARH capability have not yet been addressed in the SE work, since this would require the enactment of more complex scenarios over much longer timeframes, and linkages to logistics and sustainment models for example. Such issues are probably best addressed in closed simulations in phase 3, unless aspects emerge where detailed TTPs or human interactions need to be studied.

4.2 ARH Synthetic Environment Experimental Overview

The ARH synthetic environment experiments were undertaken within DSTO’s Synthetic Environment Research Facility (SERF). Figure 1 schematically illustrates the primary components that were integrated to form the ARH experiments and exercises. Two moderate fidelity ARH cockpits were constructed to enable aircrews (pilot and battle captain for each helicopter) to ‘fly’ through and interact with a realistic battlespace. A high-resolution view of the battlespace, as seen from the helicopters, was projected onto three screens in front of each virtual helicopter. The battlespace itself was driven by a DIS compatible wargame (ModSAF) which was in turn controlled by the high control (HiCon) team who coordinated and controlled the experiments. The wargame contained a wide range of Blue and Red forces and provided the essential feedback on the effectiveness and impact of the ARHs within the battlespace. In addition to the virtual ARHs, aviation headquarters and their command teams (HQ Team) were studied as part of the overall C2 and planning of the ARH capability.



Shared situational awareness was achieved through an information architecture built on a shared information space and on a voice plus data communication network. The data components of shared information were displayed on an advanced situational awareness concept demonstrator (MapTek – Carmen, [Kirby et al 2000]) which enabled real time visualisation of the battlespace, including the Blue force locations plus known intelligence on the Red forces and threats.

Teams of scientific observers and military SMAs closely monitored and recorded the experiments. In addition, all the voice and data information flows, DIS traffic plus videos of the air crews and headquarters team were recorded to support the analysis of the experiments. This analysis was undertaken as a two-stage process. The first stage rapidly provided an initial overview of the missions undertaken to support the after action reviews where the key lessons of the experiments were extracted. This enabled the more experienced scientific and military SMAs to extract judgements from the experiments that took into account the limitations of the synthetic environment and the players. The second stage was the experimental analyses of the vast amount of data collected, with some focus to the analysis provided by the outcomes of the after action reviews.

4.3 Impact of ARH Experiments on methodology development

As noted above, the ARH application was the first serious use of LOD's SE and the experiences have contributed to the development of the methodology for C4ISR SoS development that is the subject of this paper. Some of the more significant aspects of the methodology that became apparent as a result of this initial use of the SE are summarised below.

- The importance of creating multi-disciplinary teams. This included teaming of scientific and military SMAs to identify and analyse the key lessons from the SE experiments and to rapidly modify the TTPs and technical systems for subsequent iterations. This is the major way in which the SE can be used to develop SoS emergent behaviour

- The need for real-time information capture and analysis tools to collect the quantitative data with which to compose the MoEs. This rapid evaluation of the SE experiments allows objective direction to further iterations in system development.
- The requirement for methods to take into account the limited experience of the 'players' (military personnel fighting the synthetic battle) with the ARH capability and the advanced C4ISR concept demonstrators. Note that this was primarily achieved through the after action reviews led by the combined subject matter teams. The subjective assessment of the results of the SE experiments by the SMAs is used to temper and weight the objective measures from data analysis and quantitative MoEs. Conversely, the subjective assessments are informed by the objective metrics.
- Some insights into levels of fidelity required in the simulations. For example the very high fidelity and high-pressure battlespace environment presented to the aircrew and headquarters teams resulted in rapid immersion of the players within the synthetic environment. This was despite the relatively low fidelity of the virtual ARH cockpits.
- Recognition of a need to focus experiments and data collection and analysis, as vast amount of data can otherwise be collected. An early identification of the MoFEs, MoEs and MoPs is crucial here. Managing the scale of the SE experiments is obviously important to control the number of variables. Here too the identification of the linkages of MoPs through to MoFEs can help design smaller scale and easier controlled experiments to accelerate development of component subsystems.

4.4 Emergent Properties from ARH Experiments

As a result of the ARH synthetic environment experiments a number of key outcomes and emergent properties were identified. Some examples include:

- Identifying great synergy between the ARH nap of the earth (NOE) flying tactics and the advanced battlespace awareness system. The limited visibility afforded to the pilots when flying NOE had previously limited the ability of the aircrew to effectively synchronise and coordinate their actions. Using the battlespace awareness system, the ARHs were able to both navigate themselves and synchronised their effects even when they were physically dispersed.
- Identifying the potential for coordinated action between the ARHs and other elements of the Land Force, particularly tactical unmanned aerial vehicles, land based targeting system, and land based firepower capabilities.
  - Note that many of these potential synergies would only be achieved if a sufficient level of shared situational awareness could be achieved. Given that the ARHs will initially represent a digital island in a primarily analogue Land Force, the full potential of these synergies may not be immediately realised.
- Identifying the need to team ARHs with other reconnaissance / surveillance systems in maintaining contact with and/or reacquiring targets, particularly over long ranges.
- Changes in the balance of C2 between the ARHs and the headquarters as a result of the high level of situational awareness provided to the headquarters. This tended to shift the C2 from

a highly mission command (formerly called directive control) focused to more centralised C2 from the headquarters. This is a critical aspect of the integration of the ARH into the broader system.

5 Phase 3 - Assessment of System Performance over a Wide Range of Scenarios

The Combined Arms and Support Task Force Evaluation Model (CASTFOREM) is a closed loop, event driven time stepped, stochastic simulation of a brigade level combined arms battle. CASTFOREM allows the combat effectiveness of a combined arms team to be quantified and the impact of changes in doctrine, TTPs, organisation and equipment's to be assessed. It is a useful model for representing tactics and doctrine because of its use of decision tables, combat orders and primitive orders which provide a framework in which to simulate the human decision making process and actions of combat.

The process of scenario development involves problem definition, wargaming in a human in the loop simulation such as Janus and then 'coding' the branches and sequels for a number of courses of action into CASTFOREM for replication and analysis. In the ARH problem described thus far, the SE investigation is likely to have explored in some depth the course of action identified as most likely by the military SMAs. CASTFOREM is then able to take this information and also explore a large number of the branches and sequels associated with the range of courses of action identified during the Military Appreciation Process (MAP). In this manner the analysis can explore a greater slice of the problem space and the results are less dependent on the actions of individual decision-makers or events. The validity of the TTPs derived in a particular scenario can be tested for their generality across a wider range of situations and their impact on the overall combat effectiveness of the team can be assessed.
The process of translating the results from the SE into CASTFOREM involves three major areas.

- Identification of the key decision points, their triggers and the associated branches
- Tactics, techniques and procedures representation
- Combat system and terrain representations

The team of scientific and military SMAs assembled to plan and develop the SE provides, through the MAP and the SE experimentation, the key decision points, associated triggers and a number of courses of action. The mapping of the command & control linkages between the combat elements and the representation of the triggers in a form recognised by the simulation are crucial to CASTFOREM's ability to dynamically explore the course of action branches and sequels. Since CASTFOREM does not model all aspects of the command and control processes the information used in the decision tables is limited to threat positions, perceived intent, own position, friendly positions, mission and weapons status. Using these criteria and weighting them appropriately a generic decision table can be developed as to the best course of action given a set of situation descriptors.

In CASTFOREM each ARH mission can comprise a dynamic route/activity determined by a series of decision tables, combat and primitive orders representing the TTPs and event probabilities. Hence manoeuvre with the capability of dynamic route selection; detailed search and acquisition (multiple sensors), target hand-off and engagements based on rules are possible.

The representation of tactics, techniques and procedures in CASTFOREM is through decision tables that are like logical if-then-else statements containing conditions and actions. Through the use of decision tables complex sequences of actions can be developed that accurately represent the movement, and system interaction of the ARH. For example CASTFOREM can, to a high degree of fidelity, represent the unmasking of a ARH sensor suite, scanning for targets, masking and handing off of those targets to another ARH for engagement from a masked position using radar guided Hellfire. Once a standard set of verified TTPs has been coded into CASTFOREM the generation of an ARH mission profile becomes a process of chaining together the appropriate sets of TTPs.

The combat system and terrain representations must be consistent between the wargames, SE and closed simulations if a consistent set of interpretations is to be derived. Just as it is important that the wargame and the virtual simulation represent the entities so that a fair fight takes place, it is important that the closed simulation modelling data is consistent and the influences understood. For example in a SE a pilot may use the ARH's sensors to detect a ground target through a gap in the tree canopy. Comparing this process to a similar situation in CASTFOREM the same detection may not occur due to the representation of vegetation. In the SE, vegetation is represented as a number of discrete trees, where as in CASTFOREM the representation is at a lower fidelity and the same gap in the canopy does not exist. If such an incident occurs at a critical point in the scenario the outcome may be altered. Such differences can be accounted for if they are identified.

The translation from SE to a closed model such as CASTFOREM will not be seamless and not without a great deal of effort. If the limitations of the models are recognised and there is a sufficient level of fidelity and validation in the representation of ARH TTPs then CASTFOREM provides the tool to analyse a wide range of branches and sequels across a range of courses of actions without the overheads of a SE.

The results from a closed simulation such as CASTFOREM can inform the development of doctrine and TTPs that maximise the synergy between the elements of the combined arms team. The overall combat effectiveness of the combat team can be quantified across the range of courses of action and this information used to iteratively develop the ARH TTP and the C2 between combat teams.

6 Conclusions

We have outlined an approach to SoS modelling, applied to C4ISR systems in particular, which is producing significant results for the ARH-C4ISR integrated capability. The central role of the SE to this approach stems from an ability for the SE to allow for immersion of prototype systems and expert human users together with appropriate fidelity models of other component sub-systems. This feature firstly allows SoS, with major components of human cognition and decision making, complex new technologies and many sub-system interactions, to be effectively evaluated against metrics describing overall force effectiveness. Secondly, the SE enables SoS emergent behaviour to be developed through an iterative process of TTP and technical system modification facilitated by the experimental procedures which couple real-time quantitative metrics with subjective assessments of SMAs.

The SE approach however does not replace existing methodologies for SoS development and we use the Battlelab/RTA methodology and the C4ISR Architectural Framework approach for the initial phases of problem definition and system design. The use of closed constructive simulation as the third phase of our methodology allows the SoS to be evaluated over a much wider range of scenarios than possible with the SE and provides feedback for modifications required for system robustness to changing scenarios.

The SoS development methodology is still evolving. The Battlelab problem definition and CASTFOREM evaluation aspects are already integral to the Army Experimental Framework [AEF, 2000], but we see a need to further increase awareness of the value of also including the system design, technology concept demonstators and SE aspects to give a complete experimental approach to capability development. Over the next year we propose to apply our methodology to develop and evaluate architectures for the sensor-actor warfighting paradigm [Sensor-Actor, 2000].

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