18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Modelling Maritime Surveillance – Is Complexity Worth It?

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Abstract: The Defence Science and Technology Organisation (DSTO) currently provides Operations Research (OR) support to the Royal Australian Navy (RAN) by using a variety of modelling tools to develop, explore and analyse mission tactics for Naval Aviation assets in maritime surveillance missions. These methods range from analytical calculations using geometric information to a complex simulation environment containing many interacting entities.

Maritime surveillance missions are critical in providing effective Anti-Surface Warfare (ASuW) support to the Australian Defence Force within a medium-to-low threat environment. Within the RAN, the S-70B-2 Seahawk has the primary task of supporting ASuW operations, however other aircraft can provide a force multiplier effect in this role, should an Operational Commander consider it necessary to initiate such tasking.

The mission analysed by the Air Operations Division (AOD) of DSTO involves a number of distinct phases: a) the deployment of an aircraft to an Area of Operations (AO) to search for a Contact of Interest (COI); b) the traversing of the AO by the aircraft using a predetermined search path as a guide; c) the detection and classification of as many surface vessels as possible in the region, whilst loosely maintaining the search path; and d) the aircraft returning to base when it has reached minimum fuel reserves. The MOEs used in this maritime surveillance studies are: a) the area covered during the mission, measured by examining the furthest point that the aircraft reaches during the mission before fuel has decreased to minimum reserves.; b) the percentage of contacts detected within the AO, calculated based on the number of vessels which are initially within the region, and the number of these which are detected; and c) the percentage of contacts classified within the AO, calculated based on the number of vessels that are initially within the region, and the number of these which are classified. The width of the AO is assumed to be a fixed distance.

This paper explores three particular techniques that have been used to model and investigate this maritime surveillance problem by AOD. These are: (1) methods for using analytical formulae and calculations to provide insights based on geometric information, such as entity speeds, orientations and radar ranges; (2) a Simulink®-based simulation framework, which contains low fidelity representations of entities but includes calculations that represent the dynamism of the entities; and (3) a complex constructive simulation architecture that contains higher complexity representations of the entities such as platform motion and sensor usage, as well as more complex models of human behaviour. It also provides an example of how these methods have been used in analysing the maritime surveillance problem and examines the issue of whether a complex method adds value to providing measures of effectiveness (MOEs) and recommendations to the RAN. The advantages and disadvantages of the different methods are also discussed.

Keywords: *Maritime Surveillance, Simulation, Mission Tactics, Royal Australian Navy*

1. INTRODUCTION

The Defence Science and Technology Organisation (DSTO) provides Operations Research (OR) support to the Fleet Air Arm of the Royal Australian Navy (RAN). The role of OR for this task has encompassed three primary areas: the development and refinement of Concept of Operations; the provision of infrastructure for advice on capability enhancements; and the provision of capacity for the identification of capability against particular opponents (Chandran et al., 2005). In recent times, the focus of this support has concentrated on two prime areas:

1. Examining the operational effectiveness of the Pre and Post SEA1405 Seahawk, by considering the effect of the Forward-Looking Infra-Red (FLIR) and Electronic Support Measures (ESM) upgrades on surveillance capability and aircraft vulnerability.
2. Comparing the baseline capability of other navy aircraft to conduct maritime surveillance.

Air Operations Division (AOD) of DSTO has used a number of techniques to explore and analyse operations for Naval Aviation assets within maritime surveillance missions. This paper presents an overview of some of the problems faced in modelling maritime surveillance by considering a particular mission, as well as a description of three methods and modelling techniques used. Some indicative results from a recent study are presented as a case study, and a summary of the benefits and limitations of each approach is provided.

2. THE MARITIME SURVEILLANCE PROBLEM

Following consultations with the RAN, a number of aspects of a maritime surveillance mission that are critical to its success have been identified and documented by DSTO. The objective of the mission for the naval helicopter is to locate a maritime contact of interest (COI) in an area of operations (AO) of fixed width L nautical miles (NM) in the open ocean environment. Whilst undertaking this task, the aircraft operators aim to monitor as much surface activity as possible. In particular, the mission is decomposed into a number of tasks, which are:

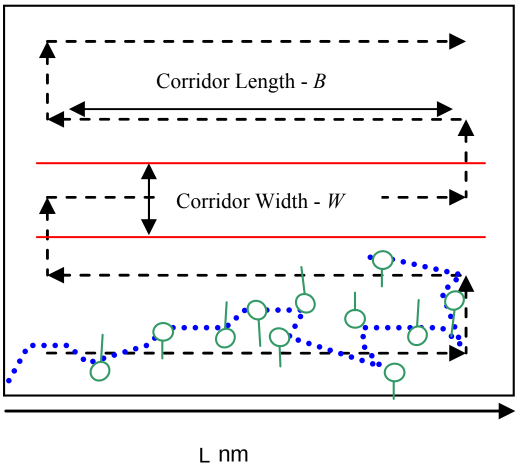

Figure 1. One Example of a Predefined Search Path (Black Dotted Line) in a Maritime Surveillance Mission, with the Blue Dotted Line Representing Aircraft Deviations to Classify Contacts

- Firstly, the aircraft is deployed on board a RAN warship transiting to the AO following intelligence that a COI is located within the region. A COI may be designated as a suspicious vessel or potential threat.
- Second, the aircraft takes off and climbs to an operating altitude at a certain speed to transit to a position from which the surveillance will begin. The helicopter speed v_h used is optimised so that the aircraft range can be maximised.
- Third, a predefined search path is determined as a guide to the aircraft search pattern.
- During the search, the priority is to classify the COI; however every effort is made to detect and classify as many moving surface vessels as possible transiting with speed v_s within the AO. The density of vessels within the AO is defined as ρ. 'Detection' of a contact is defined as 'obtaining a signal from a sensor that a contact is located within sensor coverage'. 'Classification' of a contact is defined as 'categorising a contact into a type of vessel following detection' and is undertaken at a range closer than and following detection. The vessels transit in the direction of a shipping lane.
- The aircraft continues along its search path until it has reached minimum fuel reserves and must return to the warship. Figure 1 shows a search path determined through discussions with the RAN, along with surface vessels located in the AO.

The purpose of AOD's OR support is to compare the capability of a number of different navy assets to conduct maritime surveillance. The main factors that vary between aircraft are sensor capability (different radar detection ranges and visual imaging capabilities) and platform capability (different fuel capacities, fuel flow rates and operating speeds).

Comparisons between the aircraft are based on a number of measures of effectiveness (MOEs) that are used to distinguish between their relative capabilities, such as area covered, percentage of contacts detected and percentage of contacts classified.

3. TECHNIQUES TO MODEL MARITIME SURVEILLANCE MISSIONS

This section discusses three methods that have been used by AOD to undertake OR to examine the maritime surveillance missions. The objective of these methods is to provide a capability for the RAN to examine different tactics and procedures and obtain outcomes to assist them in making key decisions about these tactics prior to undertaking live exercises or missions. These methods described here are: the use of analytical calculations and formulae; a simulation framework containing low fidelity representations of systems; and a complex constructive simulation framework containing high fidelity representations of systems. The links between the operational question and the methods are shown in Figure 2.

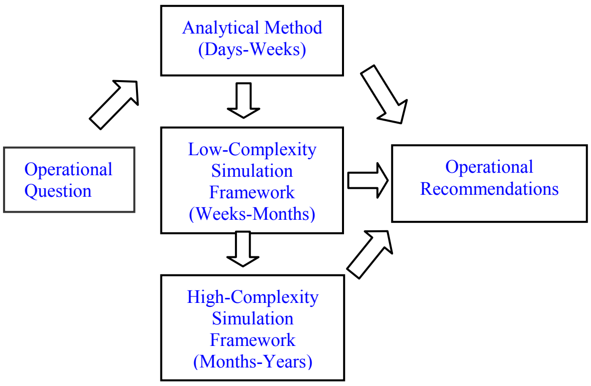

Figure 2. The Links between the Operational Question, Methods and Recommendations

3.1. The Analytical Approach

The objective of the analytic approach is to develop a simple model that provides some insight into the surveillance problem, using a series of simplified calculations to produce a quantitative solution. Using this approach, two examples are provided: a) an analytic model to optimise a maritime search strategy; and (b) a calculation of the effect of vessel movements on the number of vessels classified.

The helicopter employs a search pattern as illustrated in Figure 1. This can be viewed as a succession of corridors of width W. In the first example, the helicopter travels at a constant speed v_h, progressing along a corridor from one point at which a contact is classified (classification point) to the next in a constant direction. The Measure of Effectiveness E for optimising the search strategy is the area covered per unit time A/t. The optimum corridor width W_{opt} is the width W that maximises E.

For a statistical model, classification points can be generated from a uniform, random distribution on the plane with a mean density ρ. Let (x_n, y_n) denote the coordinates of classification point n. The path length for N consecutive distances between classification points is

$$P_L = \Sigma_{n=1}^{N} r_n$$

where r_n is the distance travelled from n-1 to n such that

$$r_n^{\ 2} = (x_n - x_{n-1})^2 + (y_n - y_{n-1})^2.$$

Then,

$$E = A/t = v_h W (x_N - x_0) / P_L.$$

P_L and E are statistical quantities and fluctuate based on the points obtained from the random distribution. The limit as $N \rightarrow \infty$ provides a characteristic rate E. Optimising W to maximise E is a complicated process.

To provide a simpler approach, the following hypothesis is proposed. Consider a search strategy where the helicopter employs a zigzag path as shown in Figure 3, with dimensions between consecutive classification points of

$$aW \times (1/\rho W)$$

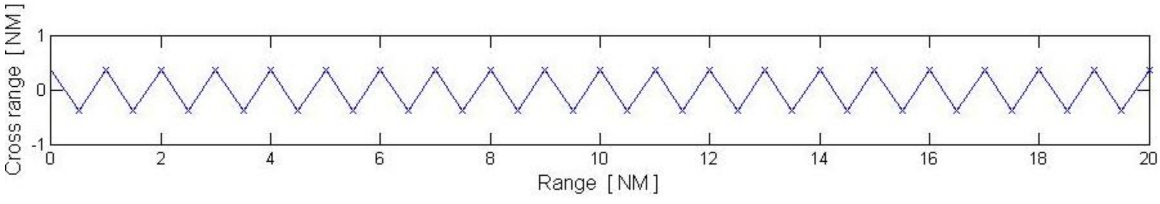

Figure 3. A Simplified Zigzag Path Employed by the Helicopter during a Maritime Surveillance Mission

where a is an adjustable parameter between 0 and 1, ρ is the mean vessel density, aW is the vertical distance and $1/\rho W$ is the horizontal distance between consecutive classification points. This path, on average, produces the same number of turns per unit length of corridor as the statistical model. The hypothesis is that this path produces approximately the same measure of effectiveness E, which means that all quantities are directly calculable. For N consecutive intervals, $P_L = N(a^2W^2+1/\rho^2W^2)^{1/2}$, $t = P_L/v_h$, $A = W(N/\rho W) = N/\rho$ and

$$E = A/t = (v_h/\rho)(a^2W^2+1/\rho^2W^2)^{-1/2}.$$

E is a function of W. Maximising E with respect to W produces

$$W_{opt} = (a\rho)^{-1/2}$$

For $a = 0.38$ (obtained through trialling lines of best fit), E and W_{opt} agree with the corresponding statistical results to within 10%.

In the second example, the effect of vessel movement on the number of vessels classified is calculated. Let P_L be the path length of the helicopter within AO of width L and $P_L > L$. If the assumption is made that *every* vessel within the corridor is classified, then the number of classifications in the AO is given by

$$N_c \cong n\rho LW$$

where $n = d_h/P_L$ is the number of corridors that the aircraft travels in and d_h is the maximum distance that a helicopter can fly before it must return to its base. The area covered

$$A_c \cong nLW$$

is independent of the speed of the vessels.

In contrast to A_c, the number of classifications N_c *is dependent* on the speed of the vessels and is given by,

$$N_c \cong \rho L[nW-(n-1)\beta\alpha P_L/2] \qquad (1)$$

where v_s and v_h are the speeds of the vessels and the aircraft respectively, B is the corridor length, $\alpha = v_s/v_h$ and $\beta = B/L$.

The second term in Equation 1 occurs because the aircraft encounters the vessels that are moving across the corridor. As it proceeds along each corridor, a proportion of the vessels that the aircraft encounters have been classified previously.

Finally, the fraction of vessels that are classified of all the vessels that were in the area during the maritime surveillance mission is given by:

$$C_{pc} \cong N_c/\rho L(nW+\alpha d_h) \qquad (2)$$

C_{pc} must always be less than unity.

3.2. The Low Complexity Simulation Framework

When conducting military OR, operational questions can be posed on short notice with a prompt response required. If certain assumptions about operational performance can be made, a flexible low complexity model alone could be used to undertake the full research. If the question is complex, the low complexity framework can be used to determine what fidelity of modelling is needed. This involves planning, designing, implementing and testing the representative models individually as well as the system as a whole (Chandran et al., 2007). This approach saves time and money and also improves our understanding of the problem.

Many of the models developed within this framework are simple. For example, the motion of the aircraft is represented by speed, location and direction in the model, as opposed to more realistic six-degree-of-freedom representations in higher complexity simulations. The models are developed and tested, to ensure that they are operational as per their specifications, and that their specification, through discussions with the RAN, is correct. Following development and testing, the user may run the simulation with the appropriate initial conditions, which include the location and speeds of surface vessels, the location and speeds of the navy helicopter and pre-briefed waypoints that the helicopter is scheduled to fly.

At the completion of an individual run, the simulation has the capability to collect certain MOE data that can be used to examine the effectiveness of the simulated mission. For these studies, data such as the number of detections, number of classifications, mission time and area covered during the mission are collected for individual runs and data from a set of multiple runs can be statistically examined, to help inform decision makers about the relative merits of different options.

3.3. The High Complexity Simulation Framework

The high complexity simulation environment has many similarities to the low complexity framework: each requires some knowledge about the systems involved; each contains models that represent the systems to some level of fidelity; each contains data processing within and between the models; and they both provide output that can be used to examine MOEs of different methods or systems.

The major additions that the high complexity simulation environment provides in examining the maritime surveillance problem are summarised below:

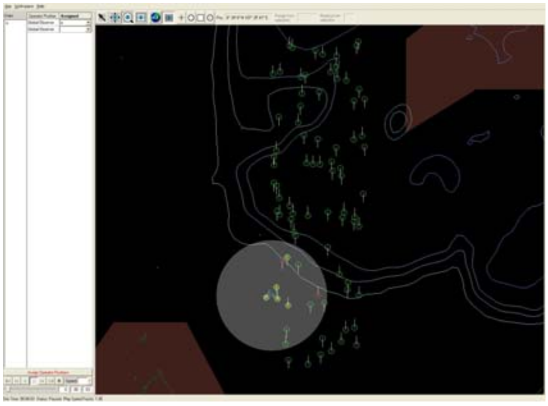

Figure 4. A Two-Dimensional Visualisation of an Individual Simulation

- The models more closely represent the real systems, and therefore require significantly more background knowledge, data and processing;
- Models of operator decision-making are more detailed, and require a significant amount of discussion between DSTO and RAN operators (Heinze et al., 2002);
- Validation and verification of models with real systems is undertaken by DSTO in conjunction with the RAN, through comparing results with technical trial data, experiments, operator experience and historical analysis. This process can be time consuming (Chandran, 2005); and
- A *significant* amount of data from different models during each simulation run can be collected and replayed visually, so that any unusual behaviours can be examined (see Figure 4).

4. SOME INDICATIVE OUTCOMES USING THE DIFFERENT METHODS

Two examples of MOEs used in OR studies to support the RAN are the total search area that the helicopter is able to cover during a maritime surveillance mission and the number of contacts successfully classified. These depend on a number of factors, including: the amount of fuel that the helicopter can carry; the operational speed, altitude and associated fuel flow of the aircraft; the amount of deviation required by the aircraft to effectively classify as many surface vessels as possible; and environmental conditions. Total search area covered and the number of contacts classified can be modelled in many ways. This section discusses how this information is used to calculate these MOEs using the three methods.

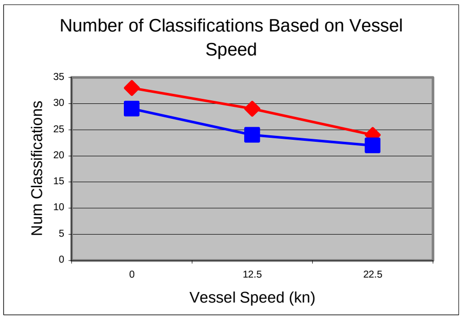

Figure 5. Comparison of Results between Analytical (Red line) and Low Complexity Frameworks (Blue line)

4.1. The Analytical Approach

In Section 3.1, a calculation of the number of vessels classified N_C, with vessels traversing the AO having a velocity v_S, was presented. Recall that $A_c \cong nLW$ and $n = d_h / P_L$. The distance d_h is obtainable when the maximum flight time of a particular aircraft is known. If an aircraft has a flight time of 280 minutes, this corresponds to a distance of approximately 430 NM based on its fuel capacity and flow.

Figure 5 shows the effect of vessel speed on the number of classifications, with parameters V_h = 90 knots, L = 80 NM, B = 55 NM, W = 25 NM, ρ = 1/280 NM^{-2}, P_L = 90 NM, and A_C = 9500 NM^2. The gradients of the lines are similar, indicating that the difference in contacts classified between the two methods is constant, regardless of the speed of the vessels.

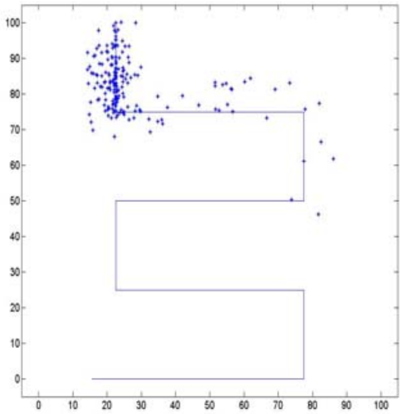

Figure 6. Final Helicopter Locations using the Low Complexity Framework. The Axes Represent Distance Travelled in Nm.

4.2. The Low Complexity Simulation Framework

Figure 6 illustrates the final helicopter locations when it has reached minimum fuel reserves and must return to the warship. This provides an insight into the search area that can be covered by this helicopter for the search tactic, using simple rules to detect and classify. Within this framework, it is relatively simple to define and populate parameters for multiple simulation runs, as well as randomise certain aspects of the scenario such as contact locations and speeds.

When running a simulation, many other MOEs, such as those identified in Section 2, are obtained concurrently, which allows post-processing of a number of MOEs on completion of the set of simulation runs. This provides an overall of aggregation of operational effectiveness, based on all of the MOEs collected.

4.3. The High Complexity Simulation Framework

Using the high complexity framework, the final helicopter locations when the aircraft has reached minimum fuel reserves over a series of simulation runs are shown in Figure 7. This provides an assessment of the search area that can be covered by the helicopter operating at a speed of 90 knots using this method.

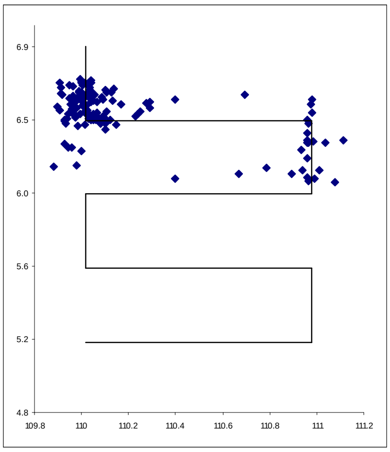

Figure 7. Final Helicopter Locations using the High Complexity Framework. The Axes Represent Distance Travelled in Nm.

As with the low complexity framework, search area is one of many outputs that can be collected from each simulation run in a high complexity framework. The main difference is that the models that process the information during a high complexity simulation run are more sophisticated and interact with each other in greater detail. Once again, the collection of several MOEs provides an aggregation of mission effectiveness.

4.4. A Comparison of Results Using the Three Techniques

Figures 8 and 9 below provide a comparison of the different OR techniques for the two MOEs examined.

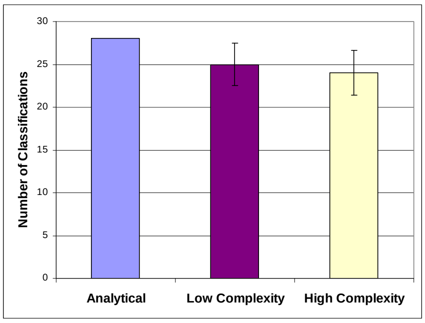

Figure 8. The Average Number of Classifications using the Three OR Techniques, and the Associated Error Bars representing the Variation for the Set of Runs

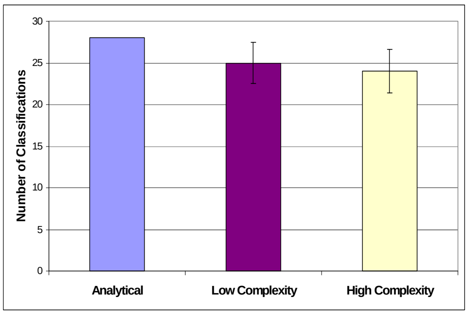

Figure 9. The Average Area Covered during a Mission using the Three OR Techniques, and the Associated Error Bars representing the Variation for the Set of Runs

The difference in results between the two simulation frameworks is not statistically significant for both the area covered and the number of classifications, based on hypothesis tests of their means being equal. This indicates that the maritime surveillance problem in this situation is sufficiently coarse that a low complexity framework is acceptable to conduct the study and provide results. *In this example, using a higher complexity framework does not add value in answering the question.* However, if more complex MOEs are required, such as detection performance in high sea states or survivability against surface threats, a high complexity simulation provides the necessary improvement in modelling fidelity to satisfy the OR support requirements.

5. LIMITATIONS AND BENEFITS OF THE DIFFERENT APPROACHES

There are a number of benefits and limitations from employing the different techniques to conduct naval OR. Table 1 summarises these issues, based on analyst experience conducting many OR studies.

Table 1. Issues Associated with the Three OR Techniques

	OR Framework		
Issues Associated with the Technique	**Analytical**	**Low Complexity**	**High Complexity**
Input data and conditions based on real systems and environmental factors	**Many Simplifications Required**	Some Assumptions Required	**High Level of Realism**
Background knowledge and understanding required about systems, scenarios and valid methods (from operators & manuals)	**Some**	**Some**	**Much**
Statistically rigorous, allowing variation in parameters	Limited	**Yes**	**Yes**
Outcomes can be visualised (simulation in motion)	Limited: Graphs/Tables	**Yes**	**Yes**
Monetary Cost	**Low**	Medium	**High**
Time to conduct a study (definition, running and post processing)	**Days-Weeks**	Weeks-Months	**Months-Years**
Credibility with RAN Operators (comprehensive insights obtained)	**Low**	Some	**High**

There are advantages and disadvantages of using the three different methods. The drivers of which method should be used are typically weighted towards time, cost and credibility. When dealing with the military, the method which provides the most comprehensive insights into the problem is seen, in many cases, as the most valuable method.

6. DISCUSSION AND CONCLUSIONS

The question of whether it is appropriate to use a complex method to solve a military OR problem is not trivial. The answer depends on the objective and constraints of the problem. Typically military OR problems range from system level to campaign level questions. The naval OR studies examined within this paper illustrate an example of mission and tactical level questions: further studies may include a greater number of interacting entities, including unmanned aerial vehicles, land-based platforms and surface-to-surface threats.

In cases where the commander's intent during a campaign is analysed, higher level methods such as military war-gaming, discussions with high level command and simple calculations may be appropriate. Conversely, examining the measures of performance of a particular military system may require in-depth analysis, including simulation using statistical as well as human-in-the-loop methods, where less complex analysis only provides limited insights into understanding the system.

Whether or not complexity is worth it depends on the assumptions that can be made that will not impact significantly on the operational aspects of the mission, and if the costs and effort required to establish the modelling infrastructure can be justified. Conversely, a more complex simulation should not be chosen purely to justify earlier costs in establishing the infrastructure.

REFERENCES

Chandran, A., Ibal, G., Tu, Z., Harvey, H. and Patterson, T. (2005), Development of Low-Level ARH Tactical Procedures Using Constructive Simulation for Operations Research, Land Warfare Conference, Qld, 4-7 October, 2005.

Chandran, A., Ibal, G., Tu, Z. (2007), Developing ARH Troop Tactics Using Operations Research Constructive Simulation, MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007.

Heinze, C., Goss, S., Josefsson, T., Bennett, K., Waugh, S., Lloyd, I., Murray, G., Oldfield, J. (2002), Interchanging Agents and Humans in Military Simulation, *AI Magazine, Volume 23, No. 2*.

Chandran, A. (2005), Complex Simulation Supporting OR for Military Decision-Making. 18th National Conference of the Australian Society for Operations Research, WA, 26-28 September 2005.