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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 71

The Second NATO Modelling and Simulation Conference

(Deuxième conférence OTAN sur la modélisation et la simulation)

Papers presented at the NATO Modelling and Simulation Group (NMSG) Conference held in Shrivenham, UK, 24-26 October 2000.

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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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The Second NATO Modelling and Simulation Conference

(RTO MP-071 / NMSG-010)

Executive Summary

The creation of the new NATO organisation for Modelling and Simulation was approved by the NAC, in 1998. This organisation was set up within the R&T organisation and consists of a NATO Modelling and Simulation Group (NMSG) reporting to the RTB, supported by a permanent office installed in RTA (Neuilly, France): the Modelling and Simulation Coordination Office (MSCO). The NMSG activity is undertaken according to an "Action plan" approved by the RTB and revised annually. This action plan requires the organisation of an annual M&S conference, in order to leverage the general knowledge of NATO and PfP nations members and to facilitate cultural and technical exchanges on this relatively new M&S topic for NATO.

The second RTA NATO Modelling and Simulation Conference was hosted by the UK MOD, in conjunction with the 3rd International Synthetic Environment Conference (ISEC), and was held at the Royal Military College of Science at Shrivenham 24 to 26 October 2000.

The Conference presented a series of papers during plenary sessions designed to provide an overview of NATO M&S current best practices, standards, interoperability and reuse. The Conference also provided information on NATO M&S policy, and new M&S activities within the Alliance. In addition the Conference also addressed themes of research, development and the application of Synthetic Environments.

The main objectives selected for the Conference were the following:

1. Provide a forum to present and discuss NATO M&S best practice and policy,
2. Provide an overview of current and future NATO M&S activities pertaining to both the development and employment of M&S, to include impact assessments and lessons-learned,
3. Present briefings on the latest M&S-related technology developments, relating to NATO Research and Technology Organisation (RTO) activities and those emerging elsewhere,
4. Discuss updates on M&S-related standards activities (including both NATO Standards Agreements and commercial standards),
5. Provide a forum to present research, development and the application of Synthetic Environments.

The conference was organised in 6 sessions: 25 papers or presentations were provided. Many enriching questions and discussions were raised and the audience expressed its satisfaction with the high standard of papers and presentations. The proceedings contains a technical evaluation of the conference, copies of published papers and, exceptionally when papers were not available, a copy of the presentation.

Key outcomes and conclusions from the Conference were:

a. The importance of M&S within NATO remains high. SACLANT reaffirmed that M&S will provide strong support in the key areas of defence planning, training & exercises, support in military operations and in CDE (Concept Development and Experimentation).

b. It was generally accepted that Synthetic Environments and M&S will be successfully applied to equipment capability and operational support & training, but their application to real-time decision making (defence policy, programmes and balance of investments) will be a more difficult and longer-term problem.

c. The first NATO Federation of simulations (the Distributed Multi-National Defence Simulations - DiMuNDS 2000 Project) was successfully demonstrated at the Conference. This impressed attendees by the demonstrative impact of the federation of simulations and the prospect it provided for future Computer Assisted Exercising (CAX) capabilities to support, in particular, the NATO CJTF.

d. The Synthetic Environment Data Representation and Interchange Standard (SEDRIS™) that provides the means to represent environmental data (terrain, ocean, air and space), and promote the unambiguous, loss-less and non-proprietary interchange of environmental data is becoming more widely used within the M&S community and is now likely to be recommended as a NATO STANAG.

e. The integration of human behaviour at different levels within simulations will remain a very difficult problem and challenge for the M&S community.

f. Major General A C Figgures, Capability Manager (Manœuvre) UK MOD, provided the Conference with a fitting end message encouraging the SE and M&S community "to continue their efforts, without forgetting the primary objectives of providing military personnel with effective, affordable SEs which are also credible to military and scrutiny staffs. SEs must be led by Customer *pull* and not by Technology *push*".

Deuxième conférence OTAN sur la modélisation et la simulation

(RTO MP-071 / NMSG-010)

Synthèse

La création d'un nouvel organisme OTAN de modélisation et simulation (M&S) a été approuvée par le NAC en 1998. Cet organisme a été créé au sein de l'Organisation pour la recherche et la technologie de l'OTAN (RTO) et consiste en un Groupe OTAN de modélisation et simulation (NMSG) qui rend compte au RTB et qui dispose d'un bureau permanent dans les locaux de la RTA à Neuilly (France) : le bureau de coordination des activités OTAN de modélisation et simulation (MSCO). Les activités du NMSG sont entreprises dans le cadre d'un "Plan d'action" approuvé par le RTB et revu tous les ans. Ce plan d'action prévoit l'organisation d'une conférence M&S annuelle, qui a pour objectif de sensibiliser les pays membres de l'OTAN ainsi que les pays du PpP à ce sujet relativement nouveau pour l'OTAN, ainsi que de faciliter les échanges culturels et techniques dans ce domaine.

La deuxième conférence RTA/OTAN sur la modélisation et la simulation a été organisée par le Ministère de la Défense du Royaume-Uni, conjointement avec la 3ème Conférence Internationale sur les Environnements Synthétiques (ISEC) au Royal Military College of Science de Shrivenham du 24 au 26 octobre 2000.

Lors des séances plénières, la conférence donna lieu à une série de communications offrant un aperçu des meilleures pratiques actuelles, des normes, de l'interopérabilité et de la réutilisation de la M&S dans l'OTAN. Elle a également apporté des informations sur la politique de l'OTAN en matière de M&S, ainsi que des nouvelles activités de modélisation et simulation au sein de l'Alliance. En outre, les thèmes de la recherche, du développement et de l'utilisation des environnements synthétiques ont été abordés.

Les principaux objectifs de la conférence étaient les suivants :

1. Offrir un forum pour la présentation et la discussion des meilleures pratiques et de la politique de l'OTAN en matière de M&S.
2. Donner un aperçu des activités M&S actuelles et futures de l'OTAN concernant le développement et la mise en œuvre de la M&S, y compris l'évaluation de sa portée et les enseignements déjà tirés.
3. Présenter des briefings sur les derniers développements dans le domaine des technologies de modélisation-simulation en relation avec les activités de l'Organisation pour la recherche et technologie de l'OTAN (RTO), ainsi qu'avec toutes autres activités émergentes.
4. Discuter des mises à jour des normes dans le domaine de la M&S (comprenant à la fois toutes les STANAGs et les normes commerciales).
5. Présenter un forum pour la recherche, le développement et la mise en œuvre des environnements synthétiques.

Le symposium a été organisé en six sessions : 25 différentes communications ont été présentées. Bon nombre de questions intéressantes ont été soulevées et des discussions fructueuses ont eu lieu. Les participants ont exprimé leur satisfaction devant le haut niveau des communications et des présentations. Le compte rendu de la conférence contient une évaluation technique de la conférence, des copies de communications ayant été publiées et, exceptionnellement, en cas de non-disponibilité des communications, des photocopies des présentations.

Les résultats et conclusions principales de la conférence furent :

a. La M&S présente toujours un grand intérêt pour l'OTAN. Le SACLANT a réaffirmé l'importance du soutien qui sera fourni par la M&S dans les domaines clés que sont la planification de la défense, l'entraînement et les exercices, le soutien des opérations militaires et l'activité CDE (développement de concept et expérimentation).

b. Il a été généralement admis que les environnements synthétiques (SE) et la M&S pourront être appliqués avec succès au soutien des opérations et à l'entraînement, ainsi qu'à l'amélioration des capacités des équipements, mais que leur mise en œuvre pour la prise de décisions en temps réel (politique de défense, programmes, équilibre des investissements) s'avérera plus difficile et plus longue à réaliser.

c. La première fédération de simulateurs de l'OTAN (le projet de simulations réparties de défense multinationale - DiMuNDS 2000) a été présentée avec succès lors de la conférence. Les participants ont été impressionnés par l'impact de cette "fédération", ainsi que par la perspective qu'elle fournit pour les exercices assistés par ordinateur (CAX) en particulier pour le soutien des opérations GFIM de l'OTAN.

d. La norme relative aux données pour la représentation et les échanges de données sur l'environnement synthétique (SEDRIS™) qui permet de représenter des données environnementales (terrestres, maritimes, aériennes et spatiales) et de promouvoir des échanges sans pertes et exclusives de données environnementales, est de plus en plus utilisée par la communauté M&S et pourrait devenir un STANAG OTAN.

e. L'intégration du comportement humain à des niveaux différents dans les simulations demeurera un problème très difficile et un défi pour la communauté de la M&S.

f. Le Major General A C Figgures, responsable Capacités (Manœuvres) au ministère de la Défense britannique, a prononcé un discours de conclusion très adapté dans lequel il a encouragé les communautés SE et M&S à "poursuivre leurs efforts, sans oublier les objectifs prioritaires qui sont de fournir aux militaires des environnements synthétiques efficaces et abordables qui soient acceptables à la fois pour les militaires et les vérificateurs. Les SE doivent progresser sous l'impulsion de la demande de la clientèle et non sous l'effet de la poussée technologique".

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† Paper not available at time of production.

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Foreword

Following the success of the first NATO RTA Modelling and Simulation Conference held in Norfolk, USA in October 1999, a second Modelling and Simulation Conference was held in the UK over the period 24 to 26 October 2000. It was hosted by the UK Ministry of Defence and the Royal Military College of Science at Shrivenham in the UK and was held in conjunction with the International Synthetic Environment Conference. The Conference had the themes of modelling and simulation interoperability, the NATO M&S Master/Action Plan, simulation policy, new M&S activities within the Alliance and Synthetic Environments.

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Technical Evaluation Report

by
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At the turn of the century, NATO's roles are expanding (despite shrinking defence budgets) and Modelling and Simulation (M&S) is recognised as a key issue by the Alliance. Since the early nineties, the continuous evolution of the technology has demonstrated that M&S should be an unavoidable basis for the exercising and training activity, the setting of plans, the assessment of new doctrines and tactics, etc. The importance of M&S for NATO has been demonstrated by some initiatives, starting around 1995, when ad-hoc working groups, conferences, workshops and demonstrations have been organised by Alliance organisations at all levels. From those initiatives, many useful reports have been produced showing a growing interest for this subject.

But, the most significant event occurred when, by the end of 1998, the NAC with the support of both the CNAD and the MC, took the option to set up a new and dedicated organisation within the Research and Technology Organisation (RTO), recognising de facto the underlying technical character of this activity. This new M&S organisation started its activity within the RTO in the middle of 1999. However, the 2000 NATO M&S conference is already the second M&S conference that has been organised.

The ***2000 NATO Modelling and Simulation conference*** was hosted by the UK, in conjunction with the ***3rd International Synthetic Environment conference*** and was held at The Royal Military College of Science in Schrivenham (England).

More than twice the number of papers as slots were available were received by the conference Programme Committee and selection of presentations appeared difficult. However, a high quality selection of papers covering a good cross-section of M&S activities were eventually selected by the Programme Committee which were appreciated by some 180 people who attended the conference.

The conference was organised in different sessions by a grouping of papers in well identified themes in order to facilitate and generate discussions on common concerns.

Introduction

The UK introduced the Synthetic Environment (SE) concept in the early 90s. SE has a number of different definitions around the world. The UK has an official definition: ***"A synthetic environment (SE) links a consistent set of models, simulations, people and real equipment into a common representation of the world to provide consistency and concurrency across previously discrete activities, thereby achieving timeliness, cost-effectiveness and risk reduction".*** Therefore, the view in the UK is very general, similar to that of the US "Advanced Distributed Simulation" concept. The UK Synthetic Environment concept encompasses the M&S domain, since it integrates human organisations and real military systems to provide virtual worlds for different purposes. This concept has been presented at many previous conferences.

This evaluation paper is not a rigorous technical evaluation. In his closing remarks to the conference, Major General Figgures said that "SE should be led by customer *push*, not by technology *pull*". The conference was the illustration of that very perceptive sentence, since not all technology *pull*". The conference was the illustration of that very perceptive sentence, since not all papers had a technical content. The papers covered: description of organisations dedicated to M&S or SE, new projects, feedback from successful demonstrations, future researches, etc. Even if techniques or technologies were not always present in the presentations or papers, attendees showed a large interest in the information they conveyed and generally made highly favourable comments concerning the content of papers and conference organisation.

Key outcomes and conclusions from the Conference were:

a. The importance of M&S within NATO remains high. SACLANT reaffirmed that M&S will provide strong support in the key areas of defence planning, training & exercises, support in military operations and in CDE (Concept Development and Experimentation).

b. It was generally accepted that Synthetic Environments and M&S will be successfully applied to equipment capability and operational support & training, but their application to real-time decision making (defence policy, programmes and balance of investments) will be a more difficult and longer-term problem.

c. The first NATO Federation of simulations (the Distributed Multi-National Defence Simulations - DiMuNDS 2000 Project) was successfully demonstrated at the Conference. This impressed attendees by the demonstrative impact of the federation of simulations and the prospect it provided for future Computer Assisted Exercising (CAX) capabilities to support, in particular, the NATO CJTF.

d. The Synthetic Environment Data Representation and Interchange Standard (SEDRIS™) that provides the means to represent environmental data (terrain, ocean, air and space), and promote the unambiguous, loss-less and non-proprietary interchange of environmental data is becoming more widely used within the M&S community and is now likely to be recommended as a NATO STANAG.

e. The integration of human behaviour at different levels within simulations will remain a very difficult problem and challenge for the M&S community.

f. Major General A C Figgures, Capability Manager (Manoeuvre) UK MOD, provided the Conference with a fitting end message encouraging the SE and M&S community "to continue their efforts, without forgetting the primary objectives of providing military personnel with effective, affordable SEs which are also credible to military and scrutiny staffs. SEs must be led by Customer *pull* and not by Technology *push"*.

Opening session:

Welcoming Address,
by Mr M S Markin, Director General (Research & Technology) UK MOD

The speaker took the option to recall first that the UK definition for SE is larger than the somewhat restrictive view of representing the natural and human made environment. Strong messages were promoted from the R&T senior representative. For UK MoD, the main goal of SE is “To enhance the quality and efficiency of military output by establishing Synthetic Environments as an integral and proven part of the Defence Process within the United Kingdom and Internationally”. A clear and concise statement indeed. A rapid assessment of the current uses of SE in the UK has been accomplished which emphasises that the uses should be more various in the near future. A long term evolution of the potential successful application of SEs was presented distinguishing between the three major application domains, namely: equipment capability, operational support & training, real time decision making (defence policy, programmes and balance of investment). Both, the first and second domains would apparently have a promising forecast evolution, the third one should be slightly more difficult to tackle. Future management challenges were identified as economy, data reduction & analysis, synergy with operational analysis, organisational culture, commercial aspects and sustainability. Less numerous were the highlighted technical challenges (time management and multiple representation), but they were not to be underestimated. In conclusion, a very clear and attractive presentation, demonstrating the support of UK senior management to the SE activity.

Opening Address,
by Dr. Gokay Sursal, Senior scientist, NATO, SACLANT

Dr. Sursal gave the SACLANT presentation on behalf R Adm D M Crocker who was not available. This presentation confirmed the strong commitment of SACLANT to the M&S activity. SACLANT reaffirmed that M&S will provide strong support in four main activity areas: defence planning, training and exercises; support of military operations and in CDE (Concept Development and Experimentation).

This was a very good and clear presentation which provided firm encouragement to people involved in the NATO M&S activity in pursuing their ambitious programme of work.

Keynote Address, NATO,
by Mr Graham Burrows, Head of Modelling and Simulation Coordination Office (MSCO), NATO Research & Technology Agency,

Graham presented an overview of the NATO R&T Organisation that was not well known in the SE community, which is generally more interested in development than in research activities. New NATO R&T challenges have been introduced and the M&S action plan was described in some detail with respect to M&S objectives as attributed to the new M&S organisation. The newly established procedure for conducting NATO Modelling & Simulation Group (NMSG) activities was presented. The speaker underlined the importance of that process, in particular, in establishing a “3-Years Rolling Implementation Plan” of activities facilitating the forecast of allocation of resources to fund demonstration and implementation phases of projects.

Industry’s Role,
by Mr M Mansell, Chairman, UK Synthetic Environments Management Board

This was a short introduction (regretfully too short) from the industry leader, which was complemented by a more detailed and attractive presentation on behalf the UK Synthetic Environments Management Board given during the following session. Mr Mansell has chaired the SEMB for 4 years and was highly qualified to welcome attendees on behalf of the UK industry community.

Introduction to the RMCS Simulation and Synthetic Environment Laboratory (SSEL),
by Mr J R Searle, Manager, Simulation and Synthetic Environment Laboratory

This last presentation of the first session was the first of several presentations provided by members of the Royal Military College of Science, host of the conference. Born in 1995, SSEL is a young and attractive organisation. It was established primarily for education & research purposes, but has rapidly grown now covering a large scope. It welcomes not only young students, but also experienced military personnel providing them with a sound background for employment related to future M&S/ SE activities. On the invitation of the speaker, the SSEL was subsequently visited by a large number of attendees. Those visits, in conjunction with the industry demonstrations available in the exhibit part of the conference, provided a firm foundation and a practical view to the attendees, which complemented and enriched the somewhat abstract presentations of the following sessions of the conference.

Session 1: POLICY, STRATEGY & MANAGEMENT

Establishment of a more extensive and rational use of SE has forced national or international organisations to examine carefully the way for managing that activity. If new organisations are not created and adequate services are not established, the full potential of SEs cannot be achieved. Some nations have re-organised their structures to implement SEs, whilst other nations have co-ordinated the activities of SEs in their existing organisations. Many presentations of this session illustrated different ways taken by nations, trying to achieve the SE full potential. The first afternoon of the conference ended with a presentation on a very different topic: the introduction of the DiMuNDS[1] 2000 experimentation. This introduction was purposely placed in this position, in order to increase the number of opportunities of people to attend a demonstration of DiMuNDS, in the exhibit part of the conference. This very successful demonstration was presented as an excellent example of the capability and availability of the technology to help solve training issues within the Alliance.

- **A Strategy for the Provision of Infrastructure & Services in Support of Synthetic Environments**,
  by Mrs J Henderson, SECO, DG(R&T), MOD, UK

SE technology has been recognised by the UK for sometime as having a high potential for all activities of military business. Impressive demonstrations have been set up and dedicated SE organisations have been established in co-operation with the UK industry and within the MoD. But, there are some organisations within the MoD that consider current SEs have not yet demonstrated their full potential. A lack of common infrastructure and common services has been identified and this is the process that is now being corrected. Jenni Henderson clearly explained the efforts, new services and organisations that are being set up to achieve the goal of providing an adequate background for the SE community in the UK. Current and future UK efforts are consistent with the objectives proposed in the NATO M&S action plan. The Technical Evaluator warmly recommends that this paper and the attached presentation should be reviewed with the prospect of current and future co-operations with the UK.

Canada M&S organisations :

Three different presentations were provided by Canada. First, John Bovenkamp introduced the Canadian efforts at the joint level. He was followed by Lt.Col. Louis Cyr, for the Army, and by Dr. Landolt, for the Air Force. These 3 presentations showed the importance that Canada is now attaching to SEs.

- **An Integrated Canadian Approach to Concept Development (CDE), Joint Experimentation (JE) and M&S**,
  by Dr John Bovenkamp, Strategic Planner, DST Pol/ DRDC, Canada

Canada only started to reorganise for the “creation of its future forces of 2020”, in November 1998. But, there has been a rapid evolution since that date. Organisation of symposia, publication of important documents such as “Strategy 2020” or “Strategic Capability plan” have opened the door to modernisation and reorganisation. The most important document is the “concept paper on a tri-tier integrated approach to CDE/ JE/ M&S”. This three tier concept is linked to the three hierarchical levels: strategic, operational and tactical. More specifically, Tier 1 is relative to ACD (advanced concept developments), the second will deal with JE (joint experimentation) and Tier 3 will be concerned by the establishment of an environmental CDE (ECDE) activity. A project to

[1] **Di**stributed **Mu**lti-**N**ational **D**efense **S**ystem

create the Joint Experimentation Centre (JEC) was discussed which was considered to be consistent with allied initiatives and, in particular, NATO projects. This was a very important and informative presentation.

- **The Establishment of the Canadian Army Simulation Centre** ,
  by Lt Col Louis Cyr, CD, Director, Army Simulation Centre, LFDTS, Canada

The Canadian Army Simulation Centre was established in 1996, in response to the Army overall re-organisation. The presentation described in some detail this new army organisation and its missions. The Synthetic Environment Canadian concept seemed to be very close to the corresponding UK concept. The Army centre is responsible for the support to operations, combat development and training at tactical level, but the development and acquisition of Army armaments are not part of its overall mission. As in many allied nations, Canadian Army training at tactical level is based on an extensive use of the JANUS simulation, facilitating co-operation with other nations. This presentation was a clear and informative picture of the Canadian Army SE activity and projects.

- **An R & D Strategy for the Way Ahead in M&S for the Canadian Air Force,**
  by Dr J P Landolt, Defence & Civil Institute of Environmental Medicine, Canada

This presentation was different from both previous Canadian presentations, since it summarised the results of a long term study on “what new technologies and methodologies could offer to the Air Force”. The study provided a good overview of current and planned characteristics of M&S, a list of concerns which are important and equally shared by other nations and organisations. The second part of the presentation was more focused on Air Force issues. The presentation emphasised the requirements for secure networking capabilities. This is an important issue concerning the nations and the Alliance as the number of developments of distributed SEs increase.

- **Italian M&S Center Project,**
  by Col A Surian, Chief, J5 Simulation Division, Italian Joint Operations HQ

Italy perhaps is late in developing a training capability (at theatre level), when compared with some other nations, however this capability will soon be filled with; the creation of the CIMSO (the Italian “Joint Operational Modelling and Simulation Centre”) and the adopted approach which pragmatically relies on the acquisition of a common tool-set already selected by many allied partners. Colonel Surian’s presentation provided a clear and attractive overview, showing the progress accomplished so far, without avoiding potential difficulties to come.

- **SEMB Presentation**
  by Mr M Mansell, Chairman, UK Synthetic Environments Management Board

Mr Mansell completed very well his short introduction of the opening session (on behalf of UK industry), by a very attractive and largely informative presentation given on behalf of the Synthetic Environments Management Board (the UK SE steering committee and acting advisory council). He has been chairman of the SEMB for 4 years which is a key organisation responsible for advising SE technical policy. Using multimedia devices, he succeeded in giving a large and excellent overview of current activities and capabilities. After recalling past and current major projects supported by SEMB (such as FlasHLAmp, ADSE or FOAS), the applicability of SEs were reviewed according to the SEMB vision. Nine different application areas or layers in the SE activity are considered: geopolitical analysis, strategic studies, costs/logistics, war-gaming/battle modelling, warfare to-morrow, product definition, component design, costs and manufacture, product support. The importance of considering costs and cost-effectiveness in SE was emphasised and indications were given on fields in which industry could be involved and more generally how it could help. The presentation was successful and attractive. Partnership between industry and government within UK SEMB could provide a good example to other allied nations if co-operation between industry and government is not so successful or not so well organised.

SEMB is a national organisation promoting the UK national SE activity. However, in response to a question, Mr Mansell stated that the SEMB is not closed to international co-operation.

- **Introduction to the DiMuNDS 2000 project and demonstration**,
  by Dirk Coppieters, NATO C3 Agency and Joost Hammers, NL, TNO Defence Research

DiMuNDS[2] 2000 is a demonstration project supporting the preparation of the leading PATHFINDER NATO program. The importance, aim and objective of the project was clearly underlined by a short, but very convincing introduction from Lt Col Gareth Pugh of the UK MoD, given on behalf the NATO Modelling & Simulation Group (NMSG) and its subordinate Simulation Advisory Task Group (SATG) responsible for the DiMuNDS experiment.

Both presenting speakers (who were co-responsible for leading that successful project) recalled the first objective of DiMuNDS: to demonstrate that a CAX capability for training a NATO CJTF could be developed by interconnecting national operational simulations already existing using the High Level Architecture. The selected scenario and the main components of the implementing SE as distributed on a LAN were described. Five nations co-operated : France, Germany, the Netherlands, the UK and the US. Adjacent to the conference theatre, a DiMuNDS 2000 demonstration was provided. Many visitors were welcomed, attracted by the excellent introduction of both project leaders. A large majority of the visitors stated that they were impressed by the demonstrative impact of the federation of simulations and the prospect it provided for future CAX capabilities.

[2] **Di**stributed **Mu**lti-**N**ational **D**efense **S**ystem

Session 2 : BUILDING SYNTHETIC ENVIRONMENTS, INTEGRATION AND STANDARDS ISSUES

- **Emerging ISO Standards for the Representation of Physical Environmental Data**
  by Dr J C Cogman, Thomson Training & Simulation, UK

This presentation was mainly focused on standardisation issues and appeared to be complimentary to SEDRIS tutorials organised before and at the end of the conference. A clear distinction was established between what many people now call “SE” and what should be named “Synthetic (or Simulated) Natural Environment”: a unique slide (the third one of the presentation) provided a clear demonstration of how different requirements could be merged in SEs. Interoperability is the big issue and defines the requirements for standards. The standardisation process selected by the SEDRIS organisation was described and the related schedule which is important for the M&S community was announced. SEDRIS appears as a very sensible approach. The presentation was of significance to the M&S community. The presentational talents of the speaker made this presentation one of the best of the conference. Many questions were posed primarily related to the standardisation process.

- **Promoting re-use in Synthetic Environments by developing Generic SE Components**
  by Mr R Smith, Matra BAe Dynamics, UK

This presentation was an overview about interoperability issues provided by a company largely involved in the M&S world. It provided an interesting feedback from their own experience. Many interesting and very general issues were raised: how to navigate around the continual evolution of technology and standards (the DIS versus HLA dilemma), how to impose a common standard to the whole Matra BAe Dynamics company? MBD found an original solution named SE-API providing a DIS/HLA highway. No other choice was made available, however it allows users to defer their choice between DIS and HLA, to reuse existing models without forcing them to be upgraded to a new standard. Some examples of applications were presented. For new components, “genericity” is the rule and standardisation has shown its importance in that process. This experience is at an early stage, but there has already been some interest shown in this approach. This process provides an alternative to a voluntary process, that of the imposition of a unique standard: only, the future will reveal what is the best policy …

- **The Use of DIS and HLA for Real Time Virtual Simulation – A Discussion**
  by Mr J Steel, Cranfield University, RMCS Shrivenham, UK

A controversial subject, but addressed here in an original, apparently neutral and pragmatic way. The study presented by the speaker is really a great step forward even if restricted on the use of both standards for real time applications. Many important aspects have been studied in the comparison of both standards which produced an attractive presentation and a well documented paper, easy to read and recommended. This was considered by the Technical Evaluator to be worthy of more detailed attention. Nevertheless, all questions had not been treated in the paper and the reader is strongly encouraged to pursue his study. One of the best papers of the conference: since it coupled with the two previous ones and, overall, it provided the best session of this annual conference!

Session 3: BUILDING SYNTHETIC ENVIRONMENTS, REPRESENTATION ISSUES

- **NATO Long Term Scientific Study on Human Behaviour Representation**
  By Dr U Dompke, ITIS at the Federal Armed Forces University, Munich, Germany

Uwe reported on the recent work completed by NATO on the very difficult problem of integrating human behaviour at different levels within simulations. Forecasting what will be the future of that activity for the next 15 years and predicting what important progress could be accomplished is a real challenge. There is not doubt than significant improvements have to be completed before the set of listed technologies can provide the results they promise. This presentation raised more issues than solutions to the problems. But, the work completed has the merit of clearly exposing what problems are outstanding and to make recommendations for improving the way research is undertaken to solve these important issues.

- **Synthetic Environments – The Met Office Approach**
  By Dr B Golding, The Meteorological Office, UK

This was one paper issued by a “non defence organisation” which raised issues how the UK MET office considers the SE business: the audience was not disappointed. The speaker highlighted the tremendous progress that could be achieved by integrating effects of dynamic environment within models and simulations. Apparently, co-operation between the MET office and military organisations has been fruitful since the office understands clearly what are the requirements of “simulationists”.

When simulations need to be very realistic, the paper advises practitioners to re-examine how they need to take into account meteorological conditions: weather evolves continuously in real world (the concept of “dynamical” weather as opposed to the “static” view often provided by legacy simulations), the uncertainty of weather forecasts very rarely taken into account, etc.. This was a very good paper and presentation.

- **Dynamic Terrain in the Synthetic Environment**
  By Ms R Simons, US Army STRICOM

Before using the SE term, the author clearly explained what she was referring to: this STRICOM research concentrates on the interactions between military systems (mainly land vehicles) and the dynamic natural environment. The effects of man made systems on the natural environment are very important features of the live military activity. Unfortunately, this is a characteristic rarely taken into account by current simulations. Past reasons for that were twofold: first, methodological, since no method was made available, second, technical, due to the insufficient capabilities of graphical machines for displaying detailed phenomena in real time. The STRICOM study presented interesting progress made thanks to the tessellation concept. That work demonstrated the possibility to increase capacities of future simulation systems in supporting individual and tactical training. This was an interesting paper and a good presentation.

Session 4: SYNTHETIC ENVIRONMENT APPLICATIONS, EXERCISES AND TRAINING

Synthetic Environments in Advanced Distributed Learning
By Mr M Kelly & Mr J Allen, Defence Evaluation & Research Agency, UK; presented by Mr J Allen

This paper exposed an interesting comparison and discussion into two related domains largely evolving on parallel tracks: the SE world and the advanced distributed learning (ADL) initiatives. Both communities have developed their own standards and/or have adopted some existing technologies. But, few actions have started so far to accommodate the way those two areas are interacting. By example, it is clear that ADL should exploit the SE technology and that the SE world could benefit from some Internet technologies and standards which are already largely used in the ADL activity. Two initiatives were briefly described : the UBT (Unit Based Training) initiated by the British Army and the standardisation effort for ADL named SCORM (Shareable Courseware Object Reference Model). This was an interesting subject, paper and presentation on a current concern for the NATO M&S organisation.

The use of Terrain Databases and Virtual Simulation for Dismounted Infantry Training
By Mr J Steel & Mr J D Smith, Cranfield University, RMCS Shrivenham, UK

A clear overview was presented of the very specific issues raised by the use of virtual simulation (or, more generally, SEs) for training of dismounted infantrymen. The review showed clearly the general deficiencies or drawbacks of current simulators. The RMCS has started (and already completed, in some cases) a number of related studies on SE application: highly detailed terrain databases, flight deck officer (Royal Navy) and CATT infantry modelling are three projects typical of that activity. This was an informative and easy to follow presentation. The paper is recommended for people who do not know this particular topic very well.

Tactical Weapon Simulation Systems
By Dr V Penev, Mr V Stoianov, Mr G Georgiev, Institute of Control & System Research, Bulgaria

This presentation was unfortunately cancelled.

Aircrew Mission Training via Distributed Simulation – a NATO Study

By Mr B N Tomlinson, Defence Evaluation & Research Agency, UK

The Technical Evaluator considered this to be one of the best papers and presentation of the conference. Those who know the author were not surprised. The study demonstrated that the use of SE is or will soon be a cost-effective way for collective training within NATO, for the benefit of combined operations. The technology is largely mature, nations are gaining experiences despite the fact that some aspects still require research and/or improvement. NATO will be interested in following that path. That paper, and the associated presentation, were not only interesting from a technical point of view, but the author proposed a way forward for NATO, identifying technical issues to tackle, but not forgetting that technology should be assessed with respect to operational requirements.

Computer Generated Forces Based on Tactical Application of Principles of Combat Survivability

By Prof D K McBride, Mr S Price, Dr VVVSS Sastry, Institute for Simulation & Training, University of Central Florida, USA / Cranfield University, RMCS Shrivenham, UK

This was a long and very detailed paper. The authors well identified and recalled the drawbacks of CGFs as they are available to-day. Despite the fact that the speakers rarely highlighted the terms "validity" or "validation", the main issue was how to effectively "VV&A" current CGFs. It is generally agreed that there is a need to start further studies to improve the human behaviour modelling in future CGF or more generally the military validity of those tools for training or study purposes. But, it is not clear that one should start from the simplistic model of Ball. First, this model could be mathematically valid if the stochastic independence of related events could be proved and it is already difficult to clearly identify them. Second, even if it was possible to prove the validity of the simple and attractive formula provided, it is not known how to estimate the values of the ingredients even in simple cases. This model has been used for sometime, but many people have now abandoned it due to reasons highlighted above. It should be also added that the Ball model is static in nature and the reality is naturally dynamical.

Nevertheless, the first part of this paper is recommended (the assessment of current CGFs capabilities). It is agreed that further researches should be started, but it is not clear on the proposed basis, except if it is used as a guideline. This pessimistic assessment is based on previous experiences which have demonstrated that the use of such models is neither practical, nor valid.

Exercise 'Réaction Combinée'

Mr Mike Watson, DERA, UK
M. Jean-Louis Igarza, Centre d'Analyse de Défense & NATO/ RTA/ MSCO, France

This paper provided a feedback from a real distributed and combined experiment held simultaneously, in France and UK, in June 2000. The speakers highlighted to attendees that establishing a CAX activity is possible, even in a short timeframe, and that it can be efficient due to an extensive use of modern technology, commercial tools and standards.

Session 5: SYNTHETIC ENVIRONMENT APPLICATIONS, EQUIPMENT ACQUISITION

Simulation Based Acquisition Developments at Northrop Grumman

By Dr. R Pudwill, LOGICON, US

Paper cancelled.

The provision of a web based process navigator facility to co-ordinate the applications of SE across Alenia Marconi Systems

By P Broadbent & I Page, Alenia Marconi Systems ltd, UK

Paper cancelled.

Simulation Based Acquisition in the Joint Strike Fighter Program

By Lt. Col. R. J. Hartnett, USAF & Lt Cdr Jon A "Chips" Lawler, Royal Navy, UK

This was a very interesting topic, but the presentation was too dense and long. In fact, two important topics were treated: first, Simulation Based Acquisition, second the JSF program in co-operation between US and UK. Unfortunately, both authors would or could not give a copy of their slides to the NATO M&S conference organisation. In addition, they did not provide a paper synthesising their talk. Consequently, it was not easy to summarise or assess such a presentation. For people who are disappointed not to receive a paper or a copy of the presentation and are nevertheless interested in the main topic of SBA, they are encouraged to read papers 00F-SIW-28, 00F-SIW-77 and 00F-SIW-81 presented on the same topic, during the Fall Simulation Interoperability Workshop organised by the Simulation Interoperability Standardisation Organisation (SISO), in September 2000. Two papers of the three were co-authored by the first speaker. Their content seems equivalent (or perhaps more detailed) and one may therefore be convinced that some items of information could be made available from the JSF program.

A Simulation Framework for Command and Staff Training

By Colonel Charles (Randy) Ball, USA, Program Manager, Warfighters' Simulation 2000 (WARSIM 2000), US Army STRICOM

A detailed update was provided on the main future tool of the US Army for high level training. The WARSIM 2000 program has been re-oriented for some years, to comply with the comprehensive JSIMS program. The speaker recalled the requirement and described the system in some detail. This was an excellent presentation and a good paper recommended to those people who require an exact and good overview of WARSIM.

UK Future Offensive Aircraft System (FOAS): From Requirements to Operation

By Squadron Leader Al Byford, UK, MoD and I Page & N Smith, DERA

It was of particular interest to hear from the FOAS programme. The experimental SE established for supporting the FOAS acquisition programme follows and takes profit from the previous UK programmes of FlasHLAmp, ADSE and STOW. The SE FOAS is providing a testimony of a first UK SEBA experience. The paper is interesting and well documented. It provides a limited feedback on the use of HLA, since despite the team declaring to demonstrate some HLA compliance, many federates were only supporting DIS, the RPR FOM was used as a basis and the HLA "time management" was not used! But, whatever the standard used, this experiment will demonstrate the feasibility of building a federated system, distributed on different LANs, interconnected via secure long distance networks, largely using COTS products and reusing already developed tools and simulations: this will provide a significant reason for using SEs in the acquisition process.

Conference Closing Remarks

By Major General A C Figgures, Capability Manager (Manoeuvre) UK MOD

The conference was opened by a senior person responsible for research and technology aspects and it was fitting that the conference was closed with remarks from an operational specialist. The speaker provided an important message to the SE community, encouraging the audience to continue their efforts, without forgetting the primary objectives of providing military personnel with “effective, affordable” SEs which are also “credible to military and scrutiny staffs”.

If only one sentence should be taken from the conference, it is: SE must be “led by Customer *pulls* and not by Technology *push*” !

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An Update of HLA Standards Efforts

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Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

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Introduction to SEDRIS

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‘Synthetic Environments – Managing the Breakout’

Mr M Markin
Director-General (Research and Technology)
United Kingdom Ministry of Defence
Main Building, Room 2135
London SW1A 2HB, UK

Slide 1 – Title

Message. Pleased to be able to share with you some thoughts on how we are doing with Synthetic Environments. I bring apologies from Admiral Blackham, Deputy Chief of the Defence Staff for Equipment Capability and the MOD’s three star champion for SE. I am the two star lead for SE across MOD, with special responsibility for research and the development of partnerships with external agencies. The MOD SE Co-ordination Office, where Andy Fawkes has recently taken over from Simon Mepham reports to me.

Slide 2 - Overview

Message. We are at a most significant point in the development of SE. I shall outline the MOD goal, look at where we are and then focus on the way ahead and highlight challenges for the future.

Slide 3 - MOD Goal

Message. SE are a new way of doing defence business. The MOD goal is shown on the slide. The key words are ‘integral’ and ‘proven’.

I believe this goal is shared with many of our colleagues in Industry.

Slide 4 – Current Status – Overview

Message. Where then are we? The technical community has demonstrated that Synthetic Environments can be built and operated. A small number of forward looking ‘customers’ have decided to invest their own funds in developing SE to support their programmes. The word is spreading and more and more users are asking ‘what can SE do for me?’ We are poised to begin the ‘breakout’ from development into the ‘mainstream’. Our biggest challenge is to manage this transition, to ensure that no one remains unaware and to convince the sceptics for whom SE are ‘just another initiative’.

Paper presented at the RTO NMSG Conference on “The Second NATO Modelling and Simulation Conference”, held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

Slide 5 – Current Status – Applications

Message. The current pattern of SE use looks like this. Using a 'traffic light' convention we see that the most progress has been in those areas where:

- Simulation was already well established - such as Command, Staff and Collective training, or
- There has been a drive to improve the efficiency of our processes - such as Smart Procurement and the need for better tools for Campaign Planning and Mission Rehearsal

However, SE have, as yet, had little impact on higher level policy and Balance of Investment functions such as cross Capability Area Equipment Planning and Strategic Analysis.

Slide 6 – Current Status – Equipment Acquisition

Message. Let me expand a little for Equipment Capability. You will hear later in the programme about progress in Operational Support and Training including the NATO CAX (Diamunds 2000), Exercise Recombinee and Aircrew Training.

Turning first to Acquisition, a growing number of Integrated Project Teams within the Defence Procurement Agency are using or planning to use SE to support Acquisition. Examples are:

- The Future Offensive Air System (FOAS)
- Future Attack Submarine
- Ground Based Air Defence (GBAD)

All of these are focusing on preparation for Initial Gate – the first major hurdle in our new Acquisition process. They are thus mainly concerned with concepts of operations, statements of need and systems integration issues. They are being planned so that the SE may be expanded as the projects develop, but we have no direct experience of doing this – this is a major challenge for the future.

We should also note that:

- UK Industry now has wide experience in the use of SE to support design, integration, manufacture and management of the supplier chain

- There is growing experience with the use of SE to support Test and Evaluation

- The MOD Acquisition Management System now includes guidance to IPTs on the use of SE. This has been developed within the SE Based Acquisition (SeBA) programme and is now being refined and tested using a number of case studies.

A notable feature of all the above is that they have been conducted with joint involvement of Government and Industry prior to major contracts being awarded – fully reflecting the new spirit of enhanced partnerships encouraged by SE and advocated within Smart Procurement.

Slide 7 – Current Status –Equipment Capability

Message. Other aspects of this area remain amber or red. We have begun to use SE to support Capability Management, looking at how different families of systems contribute to the overall capability. Examples are:

- Direct Battlefield Engagement
- ISTAR (Intelligence, Surveillance, Targeting, Attack and Reconnaissance)

Logistics issues are being addressed within SeBA and also in work on the use of SE for Campaign Planning and Mission Rehearsal (CPMR).

For the ‘Reds’ (Equipment Planning and Scrutiny) we are in close discussion with those responsible for these functions and intend to move towards initial demonstrations as soon as possible.

Slide 8 – Future Developments

Message. Let me now look into my ‘crystal ball’ and attempt to extrapolate five and ten years ahead. Within five I believe that for equipment capability and operational support we will have turned the ambers to green and the reds to amber. An exception may be the use of SE to assist real time decision making due to issues of security and interface with live CIS. Within Defence Policy and BOI we should have completed some demonstrations of the use of SE giving a mixed amber/green pattern. At the ten-year point we should be facing a largely green picture and be close to achieving our goal.

Slide 9 –Research Investment Decisions

Message. This is an area where I believe SE have a major role to play. Battle winning edge depends on advances in science and technology. Defence research relies heavily on applying advances from the civil sector. In future the MOD Central scientific staffs will focus on translating defence Policy and Strategy into research parameters and making strategic investment decisions between them. Similarly the part of DERA which is to be retained within government (RDERA) will focus on research at the 'systems' and 'systems of systems' level. Examining the impact of advances in science and technology upon military capability should be a priority for SE.

Slide 10 – Enabling Facilities and Services

Message. It is one thing to expand the application space for SE but we must consider the facilities and services which make this possible. The technology for building SE, including representation of the world and the participants within it is largely here now. Shortfalls remain in a few areas, most notably cost modelling. Some issues including availability of communications and arrangements for the storage, sharing and control of access to data are the responsibility of others, but i the SE community must articulate its needs.

Slide 11 –Challenges - Management

Message. I said earlier that we are moving from 'development' to 'production', a change that will bring new challenges. Let me highlight some of the main ones:

- **Economy.** The value of SE depends on their cost. We must ensure that builders (with the active support of users) reuse SE components where this reduces cost and risk. The UK SE Management Board has endorsed, in principle, a strategy for creating a National Infrastructure and Services for SE. You will hear more of this later.

- **<u>Data reduction and analysis.</u>** SE generate large amounts of raw data and our techniques for sorting the 'wheat' from the 'chaff' are not very advanced - we must improve them. The power of SE to produce compelling visualisation must not be abused – we have all been captured by the power of computer generated images in films such as Star Wars. Really bad SE can be as seductive as good ones - it is much better never to lose credibility than to try and rebuild it after a bad experience.

- **<u>Synergy with Operational Analysis.</u>** SE do not replace OA they support it. SE provide a means of obtaining insights into parameters which are difficult to represented within OA – such as human performance or novel operations. We need to tailor the analysis tools used to the issues being examined.

- **<u>Organisational Culture.</u>** We in the SE community continue to preach to the converted. We have strong support at senior level, but need to redouble our efforts at desk level and bring new users on board through a combination of persuasion and demonstration.

- **<u>Commercial Aspects.</u>** Obtaining best value from SE demands new levels of co-operation between MOD and Industry. There are fears on both sides on issues such as security and intellectual property rights. We must demonstrate to the wider parts of both MOD and Industry how these issues may be overcome and appropriate safeguards put in place.

- **<u>Sustain the conversion.</u>** There are many examples where new tools enjoy a period of fashionable use before being quietly forgotten. We must ensure that user commitment is maintained across the whole equipment/operational life cycle. We cannot relax after the 'breakout' but must plan for long term sustainment.

<u>Slide 12 Challenges -Technical</u>

<u>Message.</u> The above are largely 'management' challenges. Let me briefly turn to some technical ones.

- <u>Time management.</u> Most SE operate in real time. It would often be useful, particularly during operational planning and training to vary time. Human players could make decisions in real time during intense play stages and the SE 'speeded up' to better focus on the outcome of decisions.

- Multiple representation. Most SE use a single level of resolution or abstraction. As we develop SE which cover an entire process – from equipment concept to disposal or from initial plan to conduct of operations – users may wish to be able to move, easily and seamlessly, between levels. This is a major challenge to which we must respond.

Slide 13 – Conclusions

Message. SE are an important new process and set of tools which can help us meet the challenges of Smart Procurement and effective Operational response in an uncertain threat climate.

Their gestation is over - we now need to take them forward into the wider defence community – a step that will bring different challenges to those in the past. Amongst these are:

- The need to widen the user community. To convince – through persuasion and demonstration - users who have not yet ‘seen the light’ and sustain those who have
- To deliver means to secure the economy of SE – infrastructure and services
- To establish a permanent capability for the conduct of operational planning and command, staff and collective training on a multinational basis
- To extend their use to more complex BOI issues affecting Equipment Planning, Force Structures and Science and Technology.

- And last but by no means least to expand to pan-government and pan-national issues in both the defence and civil sectors– how for example might an SE approach help tackle the petrol crisis?

Thank you for your attention, I wish you a stimulating and challenging conference.

Opening Address for NATO M&S Conference

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INTRODUCTION

- Good afternoon ladies and gentlemen– Admiral Crocker, Assistant Chief of Staff Policy at SACLANT HQ, was looking forward to being here today to make this opening address. Unfortunately, another unexpected pressing duty kept him from meeting this engagement, but he did ask me to express his apologies and wishes you success in your conference. So, it is a privilege and a great pleasure for me to deliver this opening address to you.

- At SACLANT, modelling and simulation is regarded as an essential element in achieving our mission. We have also been actively involved in NATO Modelling and Simulation Group's work from the beginning, especially in defining the military requirements for M&S, and we see many ways in which this technology can be exploited for the benefit of NATO.

SCOPE

- In the time available here today, I would like to briefly describe how we at SACLANT view the future for M&S and express our view on how we believe the NATO Research and Technology Organisation and the M&S world could contribute to it.

- M&S has been used as a high-level decision making tool within the military, and the commercial world for many years. However, with the changes in NATO's strategic posture, the areas of potential use in the military environment have grown in recent years.

- Today, there are numerous uncertainties concerning the level and type of missions in which NATO may be engaged. These include the full range of Crisis Response Operations over unfamiliar terrain and with an unidentified threat, as well as collective defense operations. It is extremely time-consuming and expensive to plan, exercise and train for such a wide spectrum of missions using existing capabilities. Simulation has the potential to become an essential element in preparing NATO for these missions.

- Our long-term goal should be to obtain an agreed set of relevant, affordable and effective M&S capabilities which can be used throughout NATO and the nations.

Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

- There are four major areas where modelling and simulation would improve effectiveness and achieve significant cost savings for military activities, namely: Defense Planning, Training and Exercises, Support of Military Operations and, finally, Concept Development and Experimentation.

DEFENSE PLANNING

- The principal requirement for M&S in defense planning is the need to provide a set of tools which allow defence planners to determine not only required force levels by type unit, ship, and aircraft, but also strategic and operational capabilities, as well as infrastructure, command and control structures, and other elements in the force planning disciplines. Using simulation it is possible to evaluate the potential impact of new systems and technologies without actually absorbing the cost of employing them in the field and allows us to examine the synergy between our forces. Will an improvement in one area coincidentally reduce needs elsewhere? Additionally, comparisons across services can be done to better address joint issues. Finally, there needs to be a common database and decision making tools for use by all defence planning disciplines. These tools should be available for use in all NATO headquarters and connectivity should be established between them in order to ensure the swift updating of data and transmission of plans as they are approved.

EXERCISES

- The increasing constraints on live exercises due to environmental impacts, political concerns, decreasing defense budgets and increasing safety procedures give more weight and emphasis to the use of simulation in exercises.

- It is imperative that the Staff in each NATO command continues to receive realistic training in the use of procedures and decision-making. Similarly, we need to prepare reserve staff augmentees and non-NATO staffs for participation in NATO operations.

- Simulation can be used not only to reduce exercise costs but also enable staff to practice their skills in response to a wide range of potential crisis situations. In this respect, it is critical that simulations allow staffs to function in their normal operational environment realistically, by simulating the scenario and forces in the existing C3 environment.

- At SACLANT Headquarters we strongly support the use of simulation for training and exercising in a joint context at the strategic and operational level.

SUPPORT TO OPERATIONS

- Operational planning examines particular situations and develops force packages using existing NATO forces. During the cold war, these situations were well defined and rehearsed through live exercises. Today, and in the foreseeable future, potential crises cannot be well defined in advance, and operational plans need to be more generic in nature and must be rehearsed using various assumptions with regard to, for example, the operating environment and warning time.

- Turning to the support of actual operations in real time, one of the areas in which we currently have little or no simulation assistance is in understanding the complex command and control/decision making relationships that exist between the operational commands, NATO Headquarters and the political and military leadership of individual nations.

- Simulations could also enhance our capability to accurately forecast the outcome for different courses of action as they are being discussed. When used in this way, simulations could facilitate the modification of plans, enhance decision-making and shorten the decision cycle in a rapidly changing situation.

CONCEPT DEVELOPMENT AND EXPERIMENTATION (CDE)

- The final and may be the most relevant role for simulation involves its use in support of concept development and experimentation (CDE).

- The NATO CDE initiative was originated at the NATO Summit where it was agreed that the Alliance needs a forward-looking process to develop new concepts that will improve capability and complement the existing short to medium term planning arrangements. CDE is intended to save time, money and personnel by encouraging the conduct of multinational experiments. These experiments test and validate the most promising concepts to ensure their viability before embarking on costly R&D and procurement programs.

- Concepts can involve not only technical innovation – they may include developments in the way we are organized, doctrine, training and material. They range from broad strategic ideas down to the technical systems level.

- Simulation plays a vital role, both in initial assessment and in the practical experimentation. It is our view that the NATO M&S community can play a major role in identifying how simulation can benefit this work and fostering the development of the simulation tools that will be needed.

WRAP UP

- In summary, at ACLANT, we are convinced that appropriate exploitation of simulation technology will bring significant improvements in operational training and mission readiness and play a key role in our initiatives to improve defence capability. The requirement for simulation capability is likely to be met most efficiently if NATO and national M&S resources can be harmonised.

- Therefore, we need to develop a collection of M&S capabilities according to the level of situation being assessed (strategic, operational, tactical) and the application area (training, exercises, planning, experimentation and support to real-world operations).

- In order to achieve this the simulation technology must be exploited in a cohesive, well co-ordinated manner. In our view this is a key role for the NATO M&S Group. Right now there are several simulation initiatives underway both within the Alliance and among its members and it is important that we avoid duplication. Interoperability, re-use and affordability are the key concepts that should help us in this respect.

- However, all these are no small challenge for NATO and its member nations. I believe this conference will help us to better understand what needs to be accomplished and plan our future activities.

Keynote Address

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A Strategy for the Provision of Infrastructure and Services in Support of Synthetic Environments

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1. Introduction

1.1 In recent years the role and potential of Synthetic Environments (SEs) to support Defence programmes has expanded dramatically. This expansion is highlighting a number of issues which may, if they remain unresolved, prevent the full potential of SEs being realised and exploited. These issues centre on the requirement that the provision of SE must economical. This paper describes a study which was aimed at understanding these issues and developing a strategy and programme of work to overcome them.

2. The Business Case for the use of Synthetic Environments

2.1 A SE links a combination of models, simulations, people and real equipments into a common representation of the world [Ref. 1]. By providing consistency and concurrency across previously discrete activities within the defence process, SEs make it possible to achieve timeliness, cost effectiveness and risk reduction.

2.2 SEs are already used widely in military training and the business case for their use here has been defined and accepted for some time. Within their newly expanded role into the areas of campaign planning, mission rehearsal and operational decision support, the case for the use of SEs is equally clear. In all of these cases SEs are now seen as the only cost effective means of achieving the necessary capability.

2.3 The Smart Procurement Initiative (SPI), a fundamental part of the Strategic Defence Review (SDR), recognises the unparalleled opportunities offered by SE Based Acquisition (SeBA) to support all aspects of its inception and operation. The SeBA concept envisages the use of SEs throughout the whole of the defence process cycle with particular emphasis on the early concept and assessment stages.

2.4 Currently, it is difficult to quantify the advantages of their use in this area. However, it is believed that within the context of capability management, SEs can provide unique capabilities in support of:

a. Goal based analysis. The necessary risk reduction analyses at the early stages of the development of a new military capability can be economically exercised using the diverse representations of natural and operational environments and equipment potentially available through SEs. SEs can also provide the basis for better co-ordination of the Balance of Investment (BoI) exercises required, before proceeding to subsequent procurement stages.

b. Complex systems thinking. The complexity of current and future military systems presents problems in visualising their effects and those resulting from changes to the systems and their environments. SEs can provide the tools to exercise representations of complex systems and economically present the effects of their use.

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c. Synthesis, evaluation, comparison and integration of processes, people and equipment. Using SEs it is possible to represent and visualise the use of future systems where experience is currently limited and physical experiment is impractical, unsafe or uneconomic.

d. Communication and co-operation between and within teams. SEs can provide a powerful means of communicating or illustrating requirements and capability between and within teams. In particular they can support a seamless transition from the Capability Working Groups (CWG) to the Integrated Project Teams (IPT)[1]. They are also a means of developing co-operative working within teams, especially where parallel systems development is taking place.

3. Problems in the Economic provision of Synthetic Environments

3.1 In order to maximise the business benefit of SEs, particularly in SeBA, Ministry of the Defence (MOD) policy [Ref. 1] requires economy of SE provision through the re-use of SE components, common frameworks and services across applications. In general, there is an emphasis on achieving this by maximising the use of commercial off the shelf (COTS) technology and the harmonisation of SE and other related activities (e.g. Joint Battlefield Digitization (JBD)). The problems identified with achieving this are:

a. Lack of available SE components and knowledge. Currently there is a lack of available SE components, especially those that provide Synthetic Natural Environments (SNEs), and supporting defence environmental systems, including the representation of communications, radar and sensor systems. Coupled with this, there is perceived to be a lack of readily accessible knowledge to support the development and uses of SEs.

b. Inconsistency between SE components. Attempts to construct integrated SEs have encountered a lack of consistency between the available components resulting in a loss of integrity of the SE and its representation of the real world. Under such conditions the cost of integrating such environments increases considerably, often to the point where they are uneconomic.

c. Lack of co-operation within the SE community. There is also perceived to be a lack of co-operation within the SE community. Previously, the development and use of SEs has taken place in isolation, making integration problematic. The expansion of the uses of SEs and the need for integration of distributed components, demands co-operation on both technological and economic grounds.

d. Difficulty in resourcing people, skills and equipment. A current lack of scientists and engineers with the necessary SE skills prevents the expansion of SE development and use. Those currently working in the field are often not visible or accessible to those who are in need of consultancy or support. There is a shortage of cost effective equipments (hardware and software) developed or useable for SE application.

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1 This is also the case for subsequent stages.

4. Method of Study

4.1 An initial study[2] of MOD's vision and goals for the provision of SEs in the UK resulted in the publication in June 1999 of a paper [Ref. 2]. This identified the three key facets of any supporting framework as inclusivity and openness, innovation and synthesis, and integrity and impartiality. The study further identified the concepts of a National Centre for SE and of a web based SE Community as being those concepts most likely to provide the frameworks within which the problems with the economic provision of SE could be overcome. Further work, including interviews with SE developers and users, researched all of the options and provided more information on the requirements. The results were submitted to MOD's SE Co-ordination Office (SECO).

4.2 In late November 1999 the SE Infrastructure and Services Workshop was held with 40 attendees from MOD, the DPA, DERA, industry and academia. An intensive set of syndicate sessions, designed to focus on determining the specific services required, produced a significant set of data. Post workshop analysis concluded that:

a. SEs are currently perceived as being expensive to develop and use.

b. The workshop identified with the notion that there isn't a *level playing field*. This manifests itself in many ways but is illustrated by the concept that currently system manufacturers and integrators have access to a number of development and test and evaluation environments[3]. These environments can be rented at reasonable cost and are open to all accepted users. Developers and users are in need of the SE equivalents[4].

c. The workshop showed the urgent need for the identification of a set of open specification, implementation and integration standards and frameworks for development and use.

d. The workshop highlighted the problems of ownership of knowledge, SE components and information[5] and the preservation of the Intellectual Property Rights (IPR).

e. Attendees also raised the specific concern of the current shortage of SE knowledge and skills.

5. Conclusions

5.1 There is an urgent need for a National Focus for Synthetic Environments (NFSE), which could provide the framework upon which to develop the required services. However, the current lack of such a framework should not preclude the initiation of a set of services under a temporary focus.

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2 Supported by the Synthetic Theatre of War (STOW) initiative.

3 A example would be Salisbury Plain.

4 Developers and users need the SE equivalent of Salisbury Plain.

5 Information is defined as data in context.

5.2 Under an interim NFSE, there is a need to:

a. Provide services which give access to directories and repositories of sources of common SE components, knowledge, skills and information.

b. In order to provide the required ‘level playing field’ there needs to be a set of standard SE components. These would include those SNE components that represent natural geo-spatial environments and can be used both as part of a specialised SE or integrated into larger, possibly distributed environments.

c. Identify and, where necessary, develop standards that can be applied to the development and use of SEs and for MOD and industry to apply and support these standards in all future work. Where possible, these should be internationally recognised and accepted standards.

d. Initiate the implementation of a change of culture in the UK, that will allow for the simple identification and resolution of ownership of the IPR of SE components, knowledge and information. This is likely to require a radical change in the nature of risk management and responsibility currently exercised in the SE community as well as the development of a number of standard IPR frameworks and support services.

e. Initiate a programme of education of the developers and users in the creation, technology and use of SEs.

6. Recommendations and Impact

6.1 Infrastructure

a) Programme: SECO, on behalf of the Synthetic Environments Capability Working Group (SECWG) should be designated as the Interim NFSE[6]. It should lead the introduction of an initial set of services and engender the change of culture needed to resolve the ownership and IPR problems. It is envisaged that this interim period should be for 1 year and at the end, SECO will hand over responsibility to a permanent NFSE[7] organisation.

b) Impact: Such an Interim NFSE will provide the basis for an informal SE community progressing to a formal SE Community with the permanent NFSE organisation providing leadership. It is important to engender a SE ‘community spirit’ as soon as possible. Failure to do so will only allow the continuance of the current unco-ordinated development and use of SEs.

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6 It is recognised that with the globalisation of industry in general and the defence industry in particular, such a focus will also be part of a greater, international network of information.

7 To be constituted during the interim period

6.2 Services

a) Standard SE components.

1) Programme: The Interim NFSE should instigate a programme to develop a national SE component capability. Under a designated authority, the programme should initially identify and obtain the standard set of SNE components needed to provide the consistency and integrity required by developers and users to simulate natural environments. These should include, but not be restricted to, those of the weather, geo-spatial, radio frequency and infrared spectrums. An example of such a programme is presented in Annex A. Later, the programme should be extended to include other categories of standard SE component, including standard vehicles, communication systems and sensor systems.

2) Impact: Such a capability is needed to create the SEs required by MOD, DERA, industry and academia for the necessary 'level playing field'. The inability to put such a programme in place will mean that consistent facilities will not exist for operational capability developers to economically evaluate their concepts in consistent environments.

b) Centralised source of information.

1) Programme: The Interim NFSE, together with industry should instigate a programme to create centralised sources of information to support all aspects of SE technology, knowledge, information, skills, equipment and capability. It is proposed that this would best be achieved through separate programmes to develop SE directories and repositories which would then be made available through a SE web site, as described in Annex B.

2) Impact: Such a capability is needed by SE developers and users to engender the economic reuse of knowledge, SE components, information and skills. The inability to put such a programme in place will mean that SE components will continue to be developed and used in isolation, prohibiting any major saving on effort or cost.

c) SE standards

1) Programme: The Interim NFSE should instigate a programme to identify a set of open specifications, implementation and integration standards and frameworks for SE development and use.

In addition, a programme to develop standard procedures, including those required for verification, validation and accreditation (V, V & A) of SE components, agreements and frameworks to support the issue of SE knowledge, components and information ownership is needed. Those necessary to cover the ownership of SE information and its management are particularly urgent.

2) Impact: The co-ordination that is offered by such a set of standards and frameworks, is essential to minimise duplication and increase opportunities for

component and information reuse. In the case of ownership and V, V & A, the lack of such standards and frameworks is placing constraints on component and information sharing and the market for SE components and information. The inability to put these programmes in place will severely hinder any co-ordinated developments attempting to take place.

d) Education

1) Programme: The Interim NSFE should co-ordinate a national SE education programme. An early and cost effective programme could be implemented using Computer Based Training (CBT) through the proposed web site (Annex B) and with DERA, industry and academia providing a number of higher level courses. This programme should be extended to the systems engineering courses provided by universities, colleges and private organisations such that they include sections on SEs and the techniques required to correctly implement and use them. It is believed that the techniques, formal methods and rigour that such courses instil in their students would be of major benefit to the development and use of SEs.

2) Impact: An SE education programme will not only introduce the necessary SE skills into the scientific and engineering populations but would have the added bonus of marketing the use of SEs to the systems sector. Lack of a SE education programme will only perpetrate the shortage of SE skills and hinder their uptake.

	Table 1: Contributing SE I&S Services			
Problems	Standard SE components.	Centralised SE directories & repositories.	Co-ordinated programme for SE standards.	Co-ordinated programme of SE education.
Achieving economy in the provision of SEs.	✓	✓	✓	
Lack of available SE components & knowledge.	✓	✓	✓	✓
Inconsistency between SE components.	✓		✓	✓
Lack of co-operation within the SE community.	✓	✓	✓	✓
Difficulty in resourcing of people, skills & equipment.	✓	✓	✓	✓
	Programme to develop a National SE component capability.	1. SE Web Site 2. Directory development 3. Repository development.	Programme to develop a co-ordinated set of SE Standards & frameworks.	1. SE Web Site 2. Programme of SE education
	Implementation			

6.3 The contribution that the proposed services will make to solving the identified problems is illustrated in Table 1.

7. Action Plan

7.1 During the SE I&S study it was made quite clear to the researchers that the non-MOD organisations involved in the SE community are waiting for a commitment from MOD to support the development and use of SEs. Most of the recommended programmes described above are in urgent need of a management focus as well as centralised funding. If these cannot be achieved then in the current climate, industry will not be willing to enter into the development of a national SE capability.

7.2 It is proposed that these programmes should be instigated and run over three phases. The lead for Phase 1 (1 year), should be the Interim NFSE identified as SECO. For Phases 2 (1 year) and 3, responsibility would be passed to a constituted NFSE. These phases are illustrated in Table 2.

7.3 It is recognised that a programme to develop a National SE component capability, starting with a National SNE capability, will require considerable co-ordination and investment and would expect it to come under the co-ordination of a Capability Working Group (CWG), or similar level of management with acquisition managed by an IPT. Funding could be through a Public Finance Initiative (PFI) or completely private but it would require that the capability was mandated on Government [especially military] system developments before industry would be willing to underwrite the required development.

Table 1: SE I&S Services Development

Programme	Phase 1 Interim NFSE Lead FY 00 / 01	Phase 2 NFSE Lead FY 01 / 02	Phase 3 NFSE Lead FY 02 / 03 onwards
Web Site development (1)	Design & Implement web site.	Develop & Manage Web site.	Develop & Manage Web site.
Directories & Repositories	1. Instigate programme. 2. Define requirements 3. Implement Directories 4. Start Repositories	1. Manage Directories 2. Develop Repositories	1. Manage Directories 2. Manage & Develop Repositories
Standards & Frameworks Programme	1. Instigate programme. 2. Define requirements 3. Set first standards	1. Develop Tech. Standards	Develop & Manage Tech Standards
SE component Programme	1. Instigate SNE programme. 2. Define SNE component requirements 3. Develop first SNE components	1. Develop SNE component set. 2. Define SE component requirements 3. Manage Capability	1. Develop SNE component set. 2. Develop SE component set 3. Manage Capability
Higher Education Programme	1. Implement initial CBT systems on web site(2). 2. Define syllabuses	1. Develop CBT capability 2. First Specialist courses 3. Sys. Eng. Courses	On going.

Notes:
1. A NFSE web site is seen as a fundamental support service.
2. Pre-existing CBT will be exploited.

Annex A: An example of a programme to provide a Standard SNE Database Capability

1. Many aspects of the analysis indicate that there is significant requirement for a set of standard SNE components based on defined and accepted standards. It is certain that the development of such a capability will take a long time to accomplish and therefore work must start immediately. The Interim NFSE should constitute or designate an authority to oversee the creation of a national SNE capability. It should:

   a. Identify and designate a set of [international] standards for the SNE capability including those for SNE specification, interchange, implementation and use.

   b. Identify and define those SNE components that must be available and managed in order to support the short, medium and long term SE requirements.

   c. Identify those SNE components that currently exist and make as many as possible openly, either directly or in-directly, available for use.

   d. Design and set in motion a national programme to develop those components that are not currently available and to manage the complete SNE capability.

2. Such a national capability does not imply a requirement for a national SE WAN at this stage. Eventually the set of SNE Components developed *plus* a suitable SE WAN could constitute the required 'Salisbury Plain'.

Annex B: Synthetic Environment Web Site

A National Focus for the SE web site should be developed as soon as possible, in order to support the required services. Several web sites covering SEs are currently in operation and it may be that one of these could be extended to provide required environment or a new site may be seen to be necessary. The web site could support the following services:

1. SE Education. The web site should provide a number of Computer Based Training (CBT) courses ranging from 2 to 10 minute sessions covering the basics of the use and development of SEs. Longer, more detailed courses could be provided, if the need for them on this medium is subsequently identified, but such training is probably best left to more traditional courses.

   Small demonstration SEs on the web site would support education and marketing of the capability.

2. Systems Engineering Education. Courses and literature on systems engineering are well established but are not necessarily mature. The best way of educating the visitor to the web site on such matters is the provision of case studies.

   The web site should provide an overview of system engineering concepts and how they apply to the use and development of SE and references to external sources of courses, courseware and literature.

3. Case Studies. The web site should provide access to a number of suitable (and short) cases studies. They may have to be taken from other (non-military) applications (e.g. aerospace, petrochemical, automotive). However, a study arising from the application of SEs to SPI should be included as soon as possible.

4. Directories. A set of directories of practitioners, capabilities, resources, SNE components and courses should be implemented as soon as possible.

5. Glossary of terms. A Glossary of terms should be included as soon as possible to ensure that we are using the same terminology.

6. Knowledge Base. A knowledge based system should be implemented as soon as is practicable and as an extension to a basic directory system. A question and answer (e.g. “Ask Jeeves” search engine) type of system may be very helpful to those requiring initial support.

7. Repository. A set of repositories for data, specifications, components and models should be implemented as soon as is practicable. This is a longer-term requirement and may not be economical until suitable standards and frameworks have been in place for some time. A repository would encourage re-use of components but would likely be expensive to implement and maintain.

References

1. MOD SE Policy paper, D/DG(R&T)/8/6/1/1 dated 7 Dec 98

2. The SECO vision for infrastructure and services for the support of Synthetic Environments. DG(R&T)/8/8/1/13 dated 1st June 1999.

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An Integrated Canadian Approach to Concept Development, Joint Experimentation and Modelling and Simulation

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The Establishment of the Army Simulation Centre

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An R&D Strategy for the Way Ahead in M&S for the Canadian Air Force

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Introduction

The capital-equipment programme of the Canadian Department of National Defence (DND) is strongly focussed towards commercial-off-the-shelf purchases and the life extensions of existing systems through new technology insertions. This influences the way that DND mobilizes its resources for force development, life-cycle acquisition, and training when meeting capability requirements. The use of contemporary methods in modelling and simulation (M&S) is drawing increasing attention within DND as an important way of achieving cost-effective objectives in support of this type of capital-equipment modernization process.

Defence R&D Canada (DRDC), under the direction of Directorate Science and Technology Air (DSTA), recently completed a study on some long-term initiatives in research and development (R&D) in M&S that could aid Canadian air-force objectives in capability modernization for the delivery of air power. To date, air force M&S has been confined largely to the purchase of training simulators, and the development and use of operational-research modelling tools. This paper addresses R&D issues across all of the domains of M&S application that DRDC could undertake in meeting the different air-force capability requirements. These include:

- force, doctrine and tactics development,
- acquisition, operation and support of equipment, and
- training.

'Legacy' Models and Simulations Available to DRDC

The study commenced with a compilation of legacy models and simulations having air-systems applications that are accessible to DND. Over 300 models and simulations were identified; many of these were developed in DRDC's Defence Research Establishments (DREs). These legacy items were identified according to an acronym given to each of them, their domain of application and where they were kept for safekeeping. They were then mapped against Military Air Usage, and Military Air Applications to establish how they might be used in M&S to advance the air-force capital-equipment programme.

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The domain of Military Air Applications relates to Canadian air-force doctrine and, as such, it identifies the various elements that operational experience has dictated will work best in the effective use of air power. For purposes of this study, these elements are:

- Combat Air Operations
  - Counter-Air (Control of Air Space)
    - Offensive
    - Defensive
  - Counter-Surface (including Sub-Surface action)
    - Air/Land
    - Air/Sea
- Supporting Air Operations
  - Air Transport
  - Air-to-Air Refueling
  - Combat Search and Rescue (SAR) and SAR
  - Electronic Warfare
  - Airborne Early Warning & Control
  - Airborne Command, Control and Communications
  - Intelligence Support Operation
  - Special Operations
- Ground Support Operations
  - Operations Support
    - Engineering and Maintenance
    - Environment
    - Intelligence
    - Air Traffic Control
    - Air Defence
    - Ground Defence
    - Nuclear, Biological and Chemical Warfare (NBCW)
    - Airfields Engineers
  - Logistics Support
    - Administration
    - Finance
    - Construction Engineering
    - Electro-mechanical (E/M) engineering
    - Transport
  - Command and Control

The domain of Military Air Usage encompasses the following components:

- Force Development & Doctrine
  - Strategic Planning & Concepts Development
  - Threat Analysis & Assessment
  - Operations & Contingency Planning
  - Tactics & Procedures Development
  - Doctrine Development

- Long Range Equipment Planning
    - Requirements Definition
    - Contender Bid Evaluations
    - Engineering Development
    - Maintenance & Logistic Support
    - Test & Evaluation
- Training
    - Procedures Training
    - Team Training
    - Mission Planning & Rehearsal
    - Education

These models and simulations may also be categorized according to the different levels in which they represent the real world:

- Level 1: Operational Capability (Force on Force)
- Level 2: Tactical Effectiveness (Engagements of Few on Few)
- Level 3: Systems Performance (Ensembles of Devices)
- Level 4: Physics-Based Models (Single Devices, Mathematical Models)

Over the years, DRDC and its DREs have developed a large number of physics-based and systems-level models (including those of human systems) which have been augmented by those from departmental engineering units; consequently, there is a large M&S database available in these two categories. A few tactical effectiveness models, e.g., few-on-few engagements, are included in the database that were developed by DND's operational research directorates. The defence industrial sector contributed to some of this inventory through contract work with DRDC; other models and simulations were made available through international agreements.

By way of an example on how these entities may be used, one can envisage a missile/aircraft tactical engagement where different threats and aircraft characteristics are implemented by legacy models and simulations to address specific issues that aid decision making for the air force. Results from Level 4 (physics-based models) can be fed upward into Level 3 (systems-level models) and then into Level 2 (tactical effectiveness simulations) (and vice versa if refinements are required) as computer subroutines and data tables according to the degree of complexity required.

Similarly, specific areas that are relevant to the design and use of a high-performance aircraft such as the human issues pertinent to pilot protection and performance, cockpit environmental features, airframe characteristics, weapon effects, etc. could be investigated by reusing these legacy items.

DRDC envisages that the source codes of many of these legacy databases could be 'wrapped' for reuse in federations (e.g., by employing High-Level Architecture (HLA)) for distributed simulations with planning, research, engineering and other units within

DND and with other organizations, both national and international. By employing an object-oriented, software programming approach (e.g., C++), new and legacy models and simulations would be amenable to maintenance, reuse and sharing with allied defence partners. Accordingly, by creating standardized repositories of validated legacy software, data, and environments that serve the needs of NATO, other allied concerns, DND and commercial interests, much can be achieved in the sharing of this information. Perhaps, NATO could act as a central repository for the establishment of such a database!

Relevant Scientific Issues in M&S

The study then considered the different scientific issues that should be addressed using M&S to aid capability modernization of the Canadian air force. These include:

- Constructive simulations
- Simulation-based acquisition
- Low-cost simulators
- Distributed-mission simulation
- Technology demonstration projects
- Human-systems issues

For each of these six scientific issues, a series of R&D topics were identified that DRDC could pursue. Objectives were given in terms of:

- Techniques and tools for improving the ability to simulate
- Types of air-force problems that should be addressed with M&S

From this compilation of objectives, ten priority areas were identified as having particular relevance in each of these two categories. In order to get a sense of their appropriateness to the R&D programme and importance to air-force objectives, each of these priority areas were subsequently assessed according to:

- Importance of R&D choice
- Maturity of technology
- Level of internal DRDC activity
- Level of activity elsewhere in Canada
- Level of activity in allied countries
- Infrastructure required
- Impact on joint/combined operations
- Potential for generating revenue
- Affordability
- Relevance
- Risk of failure

Development of Tools and Techniques in M&S by DRDC

The study identified the following ten priority areas that DRDC could pursue in developing techniques and tools in M&S:

- DRDC/industry exercises in constructing and using HLA federations
- R&D in computer-generated forces and human-behaviour modelling in constructive simulations
- Use of object-oriented programming languages in future simulation developments
- R&D in encryption technology to secure distributed simulations

- R&D in low-cost simulators for individual and team training
- Develop operational-analysis capability in DREs to aid in embedding new technology concepts in constructive simulations
- Alternatives to high-cost visual displays (e.g., virtual-reality concepts)
- Use of M&S in reducing costs in test and evaluation
- Continue R&D of validated/verified physics-based and systems-level models in support of evolving air-force objectives
- R&D in human-systems issues that limit effectiveness of simulators (e.g., simulator-induced sickness, motion cueing, latency issues)

Application of M&S to Air-Force Problems

The following ten technical and non-technical areas were identified as relevant for exploiting M&S in aid of air-force problems:

- Develop synthetic, Canadian littoral battlespace for use in procurement of weapon systems, and for assessing tactics and doctrine of shallow-water operations
- Develop tactical aircraft environment to assist in helicopter upgrades of weapon systems
- Develop CF-18 high-performance aircraft cockpit in support of incremental modernization and tactical-engagement training
- Assist in applying M&S in human-systems integration during early stages of equipment acquisition and upgrades
- Employ M&S in developing Canadian requirements in unmanned air vehicles and fighter aircraft
- Create weapon-system-effectiveness federation for weapon selection and associated countermeasures
- DRDC participation in newly-organized Air Force M&S Working Group
- DRDC participation in creating an officer-education plan in M&S
- Provide advice in M&S to engineering and other relevant DND directorates
- Assist in developing an effective policy for implementing simulation-based acquisition, including pilot projects that demonstrate feasibility

Conclusions and Recommendations

This study provides suggestions and recommendations for a strategy on a ‘way ahead’ in R&D in M&S that supports the broad objectives of the Canadian air force for capability modernization for the delivery of air power. It is an ambitious endeavour but necessary if DND is to remain abreast of parallel efforts in allied countries. To implement it properly will require on the part of DRDC:

- Greater awareness within air-force directorates of DRDC capabilities in M&S, e.g., the extent and nature of available legacy models and simulations in the DREs
- Greater internal DRDC coordination to ensure that there is not duplication of effort in M&S amongst the DREs and other allied agencies
- Acquiring an appropriate distributed-simulation network between the DREs to promote sharing of M&S resources
- Greater collaboration between DRDC and DND operational-analysis experts
- Greater DRDC involvement in the use of M&S in acquisition support for technical analysis of options, assessing contender bids, etc.

- Greater liaison between DRDC and industry to foster greater leverage of M&S resources
- Increasing the pool of M&S experts in DRDC to promote greater usage of M&S in the department
- Replacing current ‘stovepipe’ approach to a multi-purpose, shared environment for conducting mission-systems simulation
- Participation by DRDC in developing an appropriate organization within the air force that exploits the use of virtual and constructive simulations

This concludes our presentation of this study.

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Introduction to the DiMuNDS 2000 Project and Demonstration

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Emerging ISO Standards for the Representation of Physical Environmental Data

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Abstract

In order for standards to be effective, they have to be developed by a consensus of the users. In the case of standards for the representation of physical environment data, the users are both Military and Civil and operate in a range of different domains, from modelling and simulation through to entertainment. The SEDRIS Organization has recognised the benefits of international, commercial based standards and has chosen to work with ISO/IEC to develop standards for environmental data representation and interchange. The work of an Industry/Government team has produced a robust environmental data interchange mechanism. The related technologies include a data representation model for the physical environment (terrain, ocean, atmosphere and space), a method for uniquely classifying and identifying the objects in that model and a spatial reference model to unambiguously specify locations. The task is to transpose this technology into International Standards.

This paper reports on the standardisation process that was selected for SEDRIS, the progress and timescale for the publication of the related ISO/IEC standards and the impact that the standardisation process has had on the development of SEDRIS.

Introduction

A standard, by definition, promotes stability and permanence. The rate of technical change that we are currently experiencing, however, demands flexibility. These conflicting factors make it difficult to introduce standards into areas of technical change, such as Synthetic Environments. This is particularly true for the representation and interchange of synthetic natural environment data. The need for a common standard for database interchange has long existed in the Modelling and Simulation community, but, with the increasing use of networked simulations and heterogeneous platforms, this need has extended to the provision of interoperable representations of the Synthetic Natural Environment (SNE).

SEDRIS technology (Refs. [1], [2]) has responded to this need by developing a robust mechanism for the representation and interchange of physical environment data, i.e., 'the real world'. This paper describes how that technology is being transposed into international standards in a way that will allow flexibility and, at the same time, enhance the original, engineering based work to make it of greater value to the international Modelling and Simulation community and to users in other domains.

The paper addresses;

1. Data representation of the Synthetic Natural Environment
2. The need for standards relating to environmental data representation
3. Why it is difficult to interchange databases without loss of information
4. The available options for standardisation
5. Current status of SEDRIS related standards
6. The impact of the standardisation process on the development of SEDRIS

Data Representation of the Synthetic Natural Environment

The Synthetic Natural Environment (SNE) is an important, though not necessarily essential, part of a Synthetic Environment (SE). It is given the label 'natural' in order to distinguish it from other components of an SE, such as synthetic forces, real equipment, simulation architecture and networks. In practice, a synthetic natural environment will probably include many man-made features, such as buildings, roads and bridges. It may also include vehicles and other mobile objects, since they provide measurable attributes that describe the physical environment (Ref. [3]).

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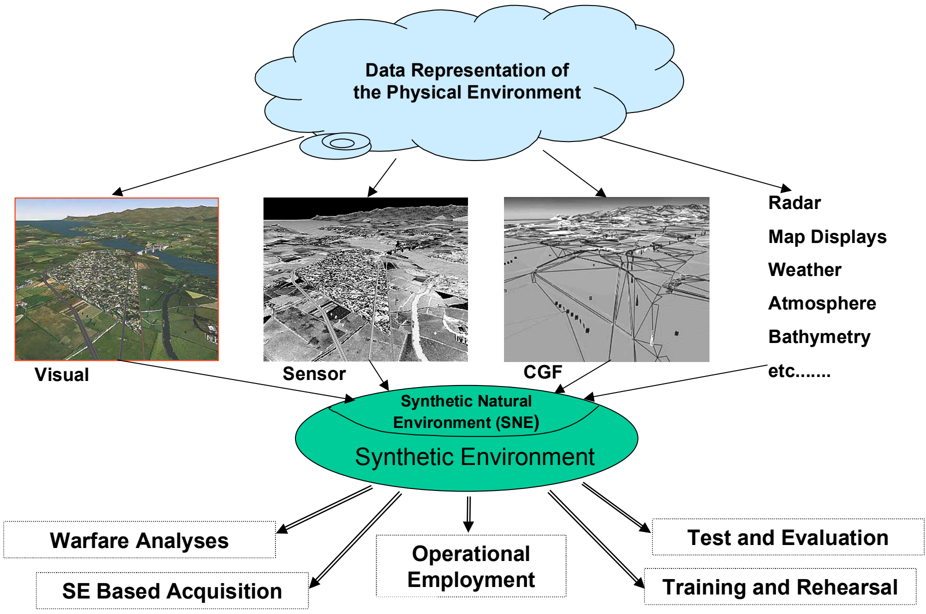

Figure 1 Data Representation of the SNE

The synthetic natural environment is a data representation of the physical world that is used by federated simulations in a networked exercise for a variety of applications. These can consist of not only the visual, IR and radar views of the environment, but also models of the atmosphere and sea bed, as indicated in Figure 1.

In a synthetic environment, there can be only one definition of the physical environment, the SNE, and for this reason it is sometimes referred to as the 'Ground Truth'. The form in which the SNE data is required for each user's run time database, however, can vary significantly. For example, the database could be for generating an image on a visual, IR or radar display, or it could be a physical model of the environment needed for CGF, or it could be an atmospheric weather model. Even if the database were required for two visual systems, there could still be differences in the designs of their respective image generators such that the environmental data had to be represented in different ways.

The goal that is sought after is for interoperability between federated simulations. There are many definitions of interoperability, but the following, adapted from Spuhl and Findley (Ref. [4]), appears the most appropriate;

'Interoperability exists when a simulation imitates all the necessary attributes of an event, such that the effect experienced by the observer is appropriate and equivalent to the same effect experienced in another simulator or experienced in the real world.'

The different forms of the SNE must therefore all agree with one another and provide a consistent view of the physical environment.

The Need for Standards for Environmental Data Representation

To achieve interoperability, it must be possible to generate run time databases from a common data representation of the environment. With reference to Figure 1, the run time databases will need to be generated from the data representation of the physical environment. This will require a standard method for data representation and a standard mechanism for interchanging that data to the formats needed by the simulation platforms.

The generated databases will need to be consistent, correlated and seamless.

- Consistent: The same set of terrain, features and attributes must be available to all users.
- Correlated: The positions of the terrain and features must be correlated and the attributes of the terrain and features must be equivalent.
- Seamless: Any differences in the way that the environmental data has been represented

must be hidden from the user. The environment should appear to be as continuous as it is in real life.

In order to support the different ways in which data is represented, it is inevitable that there will be multiple representations of the same features. To ensure that these representations are entirely equivalent and are interpreted in the same way by simulations, they must be unambiguously defined. Furthermore, the meaning of the data must not be lost or distorted during the data interchange process. To overcome these problems, SEDRIS aims to provide a technology for data representation and interchange that is;

- Representationally polymorphic
- Unambiguous
- Loss-less

These are not trivial objectives. The interchange of databases between different formats without loss of information has proved particularly difficult to achieve. SIF/HDI, published as MIL-STD-1821 in 1993, defines a standard format for database interchange. It has not been as widely adopted by Industry or Government as had been hoped. Part of the reason for this is the loss of information that occurs when a native database is converted to SIF. The rigid data structure can also give rise to some ambiguities. A study (Ref [6]), for example, showed that the time saved by interchanging an existing database via SIF, as opposed to generating a new database, was no greater than 15%.

SEDRIS technology has addressed these issues by recognising that interchange is closely related to how the data is represented. In order for SEDRIS and its associated standards to be widely accepted by Government and Industry, care has been taken to ensure that the representation and interchange of information is as loss-less, unambiguous and flexible as possible.

Data, Information, Knowledge and Understanding

To understand why it is difficult to interchange databases without a loss of information, it is worthwhile examining in more detail what is meant by data, information, knowledge and understanding. At first sight, the terms appear to be interchangeable, but on closer investigation, it is seen that they are part of a spectrum that extends from noise at the low end to wisdom at the high end (Ref.[5]). Noise becomes data when it is possible to recognise a pattern. Data becomes information when it is combined with other data in a way that adds meaning. Information integrated with other information can provide knowledge. With knowledge, decisions can be made and actions taken. If knowledge is combined with other knowledge, it can provide understanding. That is, not only is it possible to know, but also to evaluate and to anticipate. The transition from data through to understanding is achieved by adding value at each stage of the process, as shown in Figure 2.

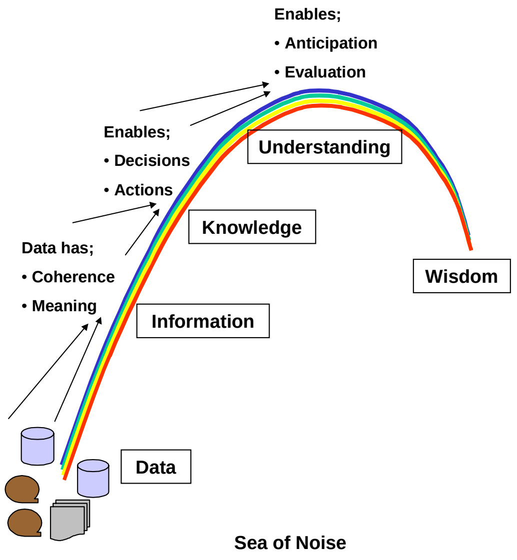

Figure 2. From Data to Understanding

How does this relate to a standard for environmental data representation? It is relevant because it provides an insight as to why data representation and interchange often involves the loss of information. A simulation database contains more than just data. It contains information and, in some cases, knowledge, since it provides meaning and allows decisions and actions to be taken. When information and knowledge are interchanged, they need to be retained as information and knowledge. As an example, consider a window in the side of a building. For flight simulation purposes, the window can be adequately represented as a texture pattern on solid surface. For a ground warfare trainer, however, a physical representation of the window is needed, since it can provide cover for a sniper. Both representations are of a ‘window’, but they convey quite different information.

SEDRIS addresses this problem by a data representation model that allows multiple representations of features; that is, by being ‘representationally polymorphic’. It also assists by defining metadata and the relationships between objects in the data model. The techniques are therefore available to preserve information, but they need to be applied with expertise, particularly in the process of generating standards for SEDRIS.

Selection of a Process to Standardise SEDRIS

To define the full meaning of the data that is to be represented requires the involvement of experts from the user domains. SEDRIS technology has been developed by the SEDRIS Associates Industry/Government team and has followed this approach by directly involving experts from the Modelling and Simulation community. When the technology was sufficiently mature to be transposed to a set of standards, a process was required that would allow a similar approach to be followed. To ensure the widest possible acceptance, it was also realised that the standards would need to be international.

There are a number of ways in which a standard can be generated. Firstly, it can be defined by an industrial organisation and, through widespread use, be accepted as a *de facto* Industry Standard. The OpenFlight® database format defined by Multigen-Paradigm is a good example of such a standard. Secondly, it can be issued as a Military Standard and it's use can be mandated. MIL-STD-1821, which defines the SIF/HDI database interchange format, is an example of this type of standard, although it’s use is no longer mandated. Thirdly, it can be defined by a national or international standards body by a process of consensus. In some ways this is similar to the first option, since an industry standard may also be subjected to consensus agreement. The difference is that for a standards body, the consensus has to be between many organisations and/or government agencies, rather than within a single organisation.

The SEDRIS Organization chose the third option for publishing standards and to use the services of ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) as the preferred standards body. ISO/IEC have established a Joint Technical Committee (JTC1), of which Sub-Committee 24 (SC24) covers standards relating to computer graphics and image processing. ISO/IEC JTC 1/SC 24 (abbreviated here to SC 24) has assigned the work on SEDRIS to Working Group 8 (WG 8), as indicated in Figure 3.

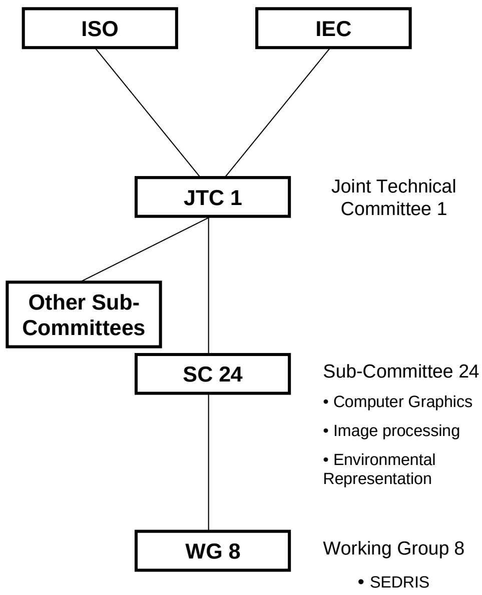

Figure 3 ISO/IEC Structure

ISO standards are voluntary. They cannot be mandated, but must be determined by market forces. Development is by consensus agreement, where consensus is defined as;

General agreement, characterised by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments.

SC 24 operates a partnership arrangement with external organisations known as a Co-operative Agreement. This allows subject matter experts and standards editors to work in close co-operation for the production of standards. It has been successfully used, for example, in producing the standard for VRML (Ref. [7]). A Co-operative Agreement has been requested between JTC 1 and the SEDRIS Organization.

The ISO/IEC process for generating standards is that successive draft versions of the documents are subjected to wider and more critical reviews. In the case of SEDRIS, working drafts are first produced that are reviewed only by WG 8. When a document is considered to be sufficiently mature, it is made into a committee draft and is reviewed at the SC 24 level. When a committee draft is considered to be complete, it becomes a draft international standard and is reviewed by all sub-committees reporting to JTC 1. The total process can take between 2 and 3 years, as shown in Table 1;

	Reviewed by;	Elapsed time for first version
Working Draft (WD)	WG 8	6 months
Committee Draft (FCD)	SC 24	18 months
Draft International Standard (FDIS)	Other Technical Committees	2 – 2.5 years
International Standard (IS)	Approved by JTC 1	3 years

Table 1 Stages in the Standardisation Process

Standards relating to SEDRIS

The SEDRIS Organization and the SEDRIS Associates have developed a technology for the data representation and interchange of the synthetic natural environment that consists of (Ref. [1]);

- A Data Representation Model, API software to access data in the model and a transmittal format
- An environmental data coding specification to provide an unambiguous description of the objects in the data representation model
- A spatial reference model to provide an unambiguous definition of location

A standard is being produced for each of these three basic concepts. Since an international standard must not be programming language specific, an additional standard that defines the language binding is produced in cases where software will need to be written.

There are currently 6 standards relating to SEDRIS that are in development, consisting of;

- SEDRIS
    - Part 1: SEDRIS Functional Specification
    - Part 2: SEDRIS Transmittal Format
    - Part 3: SEDRIS Transmittal Format Binary Encoding
- SEDRIS language binding
- Environmental Data Coding Specification (EDCS)
- EDCS language binding
- Spatial Reference Model (SRM)
- SRM language binding

The language bindings are currently for the C language only. They may possibly be extended to bindings for Java.

Current Status of SEDRIS Standard

Proposals for four new work items relating to SEDRIS, SEDRIS language binding, EDCS and SRM were submitted to ISO/IEC JTC 1 in Summer 1999. A ballot was held on the proposals, which resulted in the approval of all four proposals in February 2000. In order to expedite the work, the first meeting of SC 24 / WG 8 was held in October 1999.

Originally, it was intended that one language binding standard would serve the other three standards. It has since been realised that the EDCS and SRM should be independent of the SEDRIS standard, hence should have their own language bindings. Requests for these new work items were submitted in July and are expected to be approved by November 2000.

The current status of the standards and their forecast completion dates are given in Table 2. (See Table 1 for a definition of FCD, FDIS and IS).

	Status	FCD	FDIS	IS
SEDRIS Part 1: Functional Spec.	3rd WD	8/2001	4/2002	8/2002
SEDRIS Part 2: Transmittal Format	Not started	12/2001	8/2002	12/2002
SEDRIS Part 3: Transmittal Format Binary Encoding	Not started	12/2001	8/2002	12/2002
SEDRIS Language Binding	2nd WD	12/2001	8/2002	12/2002
EDCS	3rd WD	4/2001	12/2001	4/2002
EDCS Language Binding	Await App.			
SRM	3rd WD	8/2001	4/2002	8/2002
SRM Language Binding	Await App.			

Table 2 Current Status

Impact of the Standardisation Process

The ISO/IEC standardisation process was chosen because it would subject the standards to reviews from different perspectives and that these reviews would result in enhancements to the standards. In less than a year, some significant changes have already been made. The user interface to the SEDRIS data reference model has been simplified, plus the Environmental Data Coding Specification (EDCS) and Spatial Reference Model (SRM) standards have been made independent of the standards for SEDRIS.

ISO requires that standards should not duplicate each other. Whereas there is no technology that is directly equivalent to the SEDRIS data representation model, the same is not true for the EDCS and SRM. The Environmental Data Coding Specification (EDCS) addresses topics that are similar those for ISO 19110: Feature Cataloguing Methodology, being developed by ISO TC 211, and to the Feature and Attribute Coding Catalogue (FACC) published by DGIWG (Digital Geographic Information Working Group - Ref. [8]). The Spatial Reference Model (SRM) addresses topics that are similar those for ISO 19111: Spatial Referencing by Co-ordinates, being developed by ISO TC 211. To minimise any duplication of the work being performed, liaisons have been established with both ISO TC 211 and DGIWG. While this will no doubt slow down the pace at which the standards can be produced, it is an essential activity that should result in enhanced standards being produced by all three organisations.

Within SC 24 / WG 8, the immediate effect has been to separate the standards for EDCS and SRM from those for SEDRIS. While SEDRIS needs both the EDCS and SRM, neither EDCS nor SRM need to depend on any element of SEDRIS. They now have independent language bindings and the naming conventions have been modified to remove any references to SEDRIS.

For the SEDRIS data representation model, the read and write APIs have been rationalised and combined. This is an improvement that could have happened anyway, but was triggered by the review of the working draft for the SEDRIS functional specification, at which the opportunity for rationalisation was highlighted.

SI units have been adopted for the EDCS. Not only does this provide conformance with an existing ISO standard, but the elegance of the SI system of units will add clarity to the EDCS.

The naming of enumerated types in the EDCS has been extensively revised to remove ambiguity. Many other changes have been recommended at WG8 standards reviews. These changes will be incorporated firstly into the SEDRIS baseline release and secondly into the associated draft standards to ensure a co-ordinated update.

Conclusions

The SEDRIS technology for the representation and interchange of environmental data has been subjected to many years of critical feedback by the Industry/Government team known as the SEDRIS Associates. The feedback has been primarily from the Modelling and Simulation community. Since October 1999, SEDRIS has been subjected to even wider critical feedback from the international standards bodies that comprise ISO/IEC. This has forced the SEDRIS Organization and ISO/IEC JTC 1/SC 24/WG 8, working under a Co-operative Agreement, to take into account perspectives that are international and are from communities outside the scope of Modelling and Simulation including, in particular, Geographic Information/Geomatics.

The effect of the standardisation process has been to generate additional revisions that need to be made to SEDRIS. While this process will take of the order of 2 to 3 years, the end result will be enhanced products. In line with the original objectives, the information that will be lost in the representation and interchange of environmental data will be minimised and the ambiguities will be removed or reduced. When this has been achieved, then it is expected that the International Standards based on SEDRIS will be used by all applications requiring a data representation of the SNE. By adopting an approach that requires a consensus among a broad spectrum of users, the standards will be used because they will be fit for purpose and will be supported by both Government and Industry.

About the Author

Jack Cogman is a Senior Staff Engineer at Thomson Training & Simulation, based at Crawley in the UK. He is currently the Convenor of ISO/IEC JTC 1/SC 24/WG 8, the working group assigned to the task of transposing SEDRIS technology into International Standards.

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[2] The SEDRIS Development Project, Paul G. Foley, Farid Mamaghani, Paul A. Birkel, (Available from the SEDRIS Papers listed on the SEDRIS web site – see Ref [1])

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[8] Further information on DGIWG is available at; http://www.digest.org/

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Promoting Re-use in Synthetic Environments by Developing Generic Components

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The Use of DIS and HLA for Real-Time, Virtual Simulation – A Discussion

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ABSTRACT: *The ability of simulation systems to exchange information is of paramount importance in a synthetic environment. Both Distributed Interactive Simulation (DIS) and the High Level Architecture (HLA) via the Run Time Infrastructure (RTI) facilitate this information exchange. However, they do so in very different ways.*

This paper compares and contrasts the two methods in their use in a real-time synthetic environment (SE) involving a number of virtual and constructive simulations. The paper is presented in the form of a conversation or debate between two system developers: one who believes that DIS is sufficient for the task at hand, while the other is a firm believer in HLA. The conversation is based upon the experiences of the two developers, in using their respective method for a synthetic environment incorporating a number of generic vehicle simulators and a semi-autonomous force generator.

This conversation revolves around a number of issues that occur when using each of the two methods. These include the initial learning curve; ease of implementation; problems of inter-operability between other systems within the SE and the facility for system re-use.

Introduction

To allow distributed systems to communicate, we now have two standards: Distributed Interactive Simulation (DIS) and the High Level Architecture (HLA) via the Run Time Infrastructure (RTI). HLA-RTI is very much the newer of the two and, to some extent, has been developed to solve the problems of DIS. However, are these problems errors in perception of using DIS and does HLA-RTI, in fact, bring it's own problems that need to be resolved.

This paper investigates a number of fundamental issues that occur in distributed, real-time, virtual simulations when using DIS and/or HLA-RTI. These issues are:

- The ease of learning to use either DIS or HLA,
- The ease of implementing systems using either DIS or HLA,
- What inter-operability issues are there,
- How does DIS and HLA promote system re-use.

This investigation is presented in the form of a conversation between two fictitious system developers, **DISman** and **HLAman**. In reality, these issues are the result of actual exercises performed in the Simulation & Synthetic Environment Laboratory at the Royal Military College of Science, Cranfield University, Shrivenham, UK. Of particular interest to this paper, the laboratory contains a number of generic vehicle simulators (crewstations [1]) and a computer-generated force application [2]. The crewstations can be configured to use either DIS or HLA to communicate and, although the CGF application is solely DIS based, the laboratory has a DIS-HLA Gateway [3] that allows communication to occur with the HLA version of the crewstations.

It could be argued that, HLA is the future for distributed simulation:

> *"HLA establishes a common high level simulation architecture to facilitate the interoperability of all types of simulations and models among themselves and with other Command, Control, Communication, Computer and Intelligence (C^4I) systems as well as to facilitate the re-use of M&S components."* [4]

However, there are a number of DIS based systems in operation throughout the world and it is still used as a fundamental building block of distributed simulation systems. In the US, the

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Close Combat Tactical Trainer (CCTT), is the first of the Combined Arms Tactical Trainer (CATT) family of virtual trainers. It will train armour, cavalry, and mechanised infantry platoons on their collective tasks.

In the UK, the Combined Arms Tactical Trainer will network 66 vehicle specific simulators at the British Army's Tactical Training Centre, Warminster. An identical system will be based in Sennelager, Germany. These two systems will be able to either work independently or jointly via a wide area network.

These two systems, the US CCTT and the UK CATT, are both currently DIS based. It should be noted that there are plans to migrate the US CCTT to use HLA-RTI.

In addition, the Royal Australian Navy is in the process of linking together a number of command training simulators at the Maritime Warfare Training Centre, HMAS Watson, Sydney. The programme manager for this contract has stated:

> *"We will link these trainers using DIS protocol simply because we are not confident that HLA is significantly mature or indeed, where the technology is going. We do not want to be on the bleeding edge of technology."* [4]

Therefore, although there is a considerable drive, especially in the US, to use HLA, DIS is by no means dead.

Implementation

In this first section, our fictitious system developers discuss the implementation of DIS and HLA-RTI based applications. They discuss the available learning material, what computer languages may be used and the available systems architectures that the two frameworks allow.

DISman: There is so much to HLA-RTI that the initial learning curve is very steep.

HLAman: There is a learning curve, the steepness is very dependent on an individuals background. If they have done very little programming then yes, the curve is steep, but even a rudimentary program knowledge is often sufficient. To ease the task of developing an HLA-RTI based application, there is an enormous amount of material on the concepts of HLA [5], and programming issues using the RTI [6]. How many RTI-based applications began life as the HelloWorld or FoodFight++ applications? Indeed, there are training courses in the US and Europe [7] and at least one book on using HLA-RTI is now available [8].

The only published documentation on DIS are the various standards [9, 10, 11, 12, 13].

DISman: However, not only do these standards define DIS, they also tell one how to use it. In addition, DIS can be programmed in any computer language, under any operating system that allows basic network communication. Thus, you can write a DIS based application in Visual Basic, C or Delphi running under Microsoft Windows, or even Tcl/Tk on some obscure UNIX system.

This is because the structures of the DIS PDUs readily translate into records or structures in the relevant language. Once these structures have been defined, it is a relatively straightforward matter to populate them with the required data. The standards specify the format of this data and define the various enumerations. For example, in a detonation PDU, the different detonation results are all clearly documented, so that we can differentiate between an entity impact and an entity proximate impact.

If you are going to use HLA-RTI, you need a knowledge of the language in which the RTI implementation has been written. This is typically Java, C++ or Ada. In addition, the availability of the RTI can restrict your choice of platform or *visa versa*, that is the platform restricts your choice of RTI. For example, the US CCTT system is migrating to use HLA-RTI. However, their only choice of RTI is that supplied by DMSO as there is no other RTI for the AIX operating system that CCTT uses [14].

HLAman: The choice of programming language is restricted to the language bindings for the RTI. The DMSO RTI is available for Java, C++, Corba and Ada 95 and for quite a range of operating systems, including Microsoft Windows 98/NT, Sun Solaris, SGI Irix and Linux. Other languages can be used if a wrapper is written. For example, there is no reason why the C++ binding could not be used from Delphi.

That said a deep understanding of the intricacies of, for example C++, is not required to get up and running. The FoodFight federate example code that can be downloaded from the DMSO HLA web site [5], does not make extensive use of the language features of C++. A basic understanding of classes is all that is required, and this can often be picked up in the first few chapters of most C++ books.

You said that DIS could run *"under any operating systems that allows basic network communication"*, although this is true, the application developer must create all the necessary network interfaces. In addition, they must be able deal with the receipt of incoming network traffic. This requires the design of some form of network polling or parallel thread mechanism. The RTI, whichever version is actually used, handles all of this for you. It acts almost as part of the underlying operating system of the host computer. In fact, it can even be thought of as an addition to the operating system, extending the systems capability. In addition, HLA-RTI supports the ability to not have distributed systems, but have the federation running on a single machine.

In terms of development, as in any object-oriented programming language, careful system design is crucial and this is the case when using HLA-RTI. The design of the Simulation Object Model (SOM) and the Federation Object Model (FOM) are crucial to the operation of the federation. This typically requires a new way of thinking about the problem, whereby we divide it into a number of *components*.

Let us consider an example: The simulation of a tank moving over a terrain surface. As the tank moves there is some form of user input that allows the turret and gun to move.

When using DIS, it is typical that one computer would execute the whole tank model: the dynamics model of the vehicle moving over the terrain surface and the modelling of the articulation of the turret and gun. This forms a monolithic system brought about by the requirements of DIS and not the model. This requirement is that all of the information pertaining to a single entity must be passed within a single Entity State PDU.

Is it possible to build a more modular system, but still using DIS? Possibly, for example, we could have two separate systems simulating our tank with their information coming together into a single PDU at some time. We could use a small, local network to allow this, as shown in Figure 1.

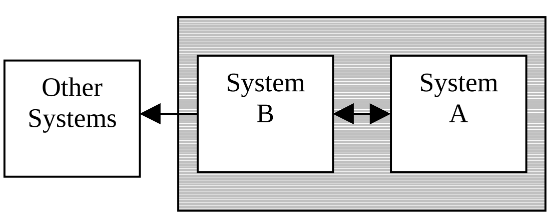

Figure 1: Distributed Entity Simulation

Here, the two systems A and B communicate with each other using their own private network. This could use DIS or a completely different protocol. In such an arrangement, System B would receive the positional information of the entity from System A and add-in the articulation information for the turret and gun. The complete record structure could then be broadcast to the remainder of the network.

So there is a workable solution for simulating components of an entity using DIS. However, HLA-RTI allows a much more logical, compact and consistent structure to be built, whereby we make use of a component architecture. Kuhl *et al.* [8] states:

> *"The HLA is fundamentally an architecture to support component-based simulation, where the components are individual simulations."*

Thus in our example of the tank simulation, we could have one simulator or *federate*, publishing information on the position of the vehicle, and a second federate publishing the articulation information of the turret and gun. Thus, we have *two* distinct components for our *single* entity. The RTI will handle the distribution of the information to the other systems for us.

This ability to build systems from components comes about by the ability to use *attributes* of an object as distinct items of data. We are no longer forced into each simulator issuing a completely valid data record containing everything about a particular entity. If we are unable to provide certain pieces of information then we are able to restrict what we make available.

We can draw an analogy between DIS and HLA-RTI with C and C++. In C, programs consist of a set of functions, which typically have global scope. In DIS, we can think of each PDU as being a function, with the PDU fields being the function arguments. Thus, when a system sends or receives a PDU, it is as though a function has been called. In such a case, all of the function arguments must be valid, and similarly all the data in each PDU must be valid.

In C++, we have the concept of a class as a means of encapsulating data and functionality within an object. In HLA-RTI, we can think of each object in a federate, as one of these base classes. The interface to an object is defined by a set of attributes, much like the public data members of a class. These attributes are made available to the rest of the federation by the *publish* and *subscribe* mechanisms. How an instance of an object manipulates these attributes, that is, the *implementation*, is hidden from the other federates. Any working variables that the object may use are analogous to the private data members in a class. Such data members are not exposed outside of the class and thus cannot be accessed. Similarly, the working data of a federate object is not available to other federates. Thus, as in a program that makes use of this object–oriented design, we have the idea of components, and we build our whole system by defining *interfaces* between these components.

Interoperability

In this second section, our developers discuss issues that occur when using the two frameworks as a means of allowing interoperability by discussing the benefits and deficiencies of the two systems.

HLAman: One of the fundamental requirements for inter-operability is that whatever you use to exchange data, it must be done reliably. With DIS, this is not the case.

DISman: This is often quoted as a reason not to use DIS, but is it true?

In a DIS-based exercise, there is no central server (either in the form of hardware or software) and systems may join and leave at any time. Thus, no one system is aware of any other system in the network. Due to this, one system cannot send PDUs explicitly to any other system, in a “reliable” fashion. This would require a unicast mechanism such as the Transmission Control Protocol (TCP). What typically happens, when using DIS, is that a system *broadcasts* PDUs over the network. When sending data packets using broadcasting there is no explicit destination address specified in that packet. Thus, there is no way that the sender of the packet can determine if *any* recipient received the correct data. This broadcasting mechanism uses the User Datagram Protocol (UDP).

Therefore, the “unreliability” of DIS is due to the “unreliability” of UDP. So rather, than say DIS is “unreliable”, what we really mean, is that there is no guarantee of delivery of data packets.

How good is this *best-effort* approach? A simple experiment, which we performed in the laboratory, can give us an idea: In a local area network of five machines, each machine sent 3,000,000 packets of data, with each packet consisting of 1024 bytes. The packets were sent at an interval of 10ms. An additional machine read the data, and verified the contents and packet order. Of the 15,000,000 packets sent, none were lost and they all arrived in the correct order. Now clearly, the next packet may be lost or arrive after some other packet. However, this is not truly “unreliable”.

HLAman: You mentioned that DIS has no central server and that no one system is aware of any other. This brings about one of the fundamental problems of DIS - the heart-beat Entity State PDUs. These PDUs are issued, typically at 5s intervals, when the state of an entity is *not* even changing. There are two main reasons why these heart-beat Entity State PDUs are issued:

- When a system joins the exercise, it will eventually hear about all of the entities currently present,
- Each system can assume that if it hears nothing about a particular entity for a period of time (the time-out period), then the system can remove that entity. This allows for the system that owns that entity to leave the exercise at any time.

Macedonia *et al.* has analysed an actual training exercise at the US Army National Training Centre, Fort Irwin, California, involving 2,191 entities [15]. During 10 hours of exercise, one third of these entities did not move and as the exercise progressed, one half became disabled and stopped all movement. However, each of these entities still issued a heart-beat Entity State PDU at a regular interval.

In another recent DIS exercise [16], involving 45 entities, of 10,982 Entity State PDUs issued, 3,060 (approx. 28%) contained no new information.

These extra PDUs do nothing but remove vital network bandwidth.

When using the HLA-RTI, each federate *actively* joins and *resigns* from the federation. When joining a federation, a federate can notify other federates that they should supply object state information, so that it can obtain the current ground-truth. Similarly, when a federate resigns from the federation, it does so in a controlled fashion, informing the other federates via the RTI. Because of the passive nature of DIS, that is, no system *actively* joins or resigns from an exercise, there is this need for these heart-beat PDUs.

However, these are infrequent situations. Obviously, they do occur, but typically, once a system is a member of an exercise, it will remain so for the duration. Yet these heart-beat PDUs are issued throughout the exercise, and so the whole exercise is being penalised simply to handle these infrequent situations.

DISman: Although, it is true that these heart-beat PDUs are an overhead, their frequency and the time-out period can be adjusted. The DIS standard does not dictate what these values should be.

This perceived problem could be greatly reduced. We could add an additional PDU to our set; one that is issued by a system as it joins the exercise. On receipt of this PDU, other systems would then transmit an Entity State PDU update for all of their entities. In addition, proper use of the Deactivated State flag in an Entity State PDU should be used to indicate that entity can be removed.

By implementing these two methods, systems can extend the time-out period and greatly decrease the heart-beat frequency and thus remove the heart-beat PDU overhead.

What we should also remember is that, the additional functionality of HLA-RTI is not for free. The simplicity of DIS imposes little overhead on the host machine. It is true that each DIS system will receive all the PDUs from every other system. This *can* impose a significant processing requirement on the host CPU. The classic example, is when we have a number of ships at sea and tanks on land that are outside the range of any form of contact. However, they still receive information pertaining to one another. This is brought about by DIS not having any data distribution mechanism (DDM). That said, it is not impossible to implement a DDM using DIS. Indeed, Macedonia *et al.* [15] consider having spatial, functional and temporal classes, whereby entities that have similar properties are members of one of these classes. Only entities within the same class exchange information. This functionality acts as an intermediary layer between the DIS PDUs and the network.

There has been considerable work in this area [17, 18, 19] and even the DIS standard talks about possible future capabilities:

> *"It may not be necessary that all participants receive all PDUs of an exercise. Mechanisms to allow for efficient use of network resources may include filtering PDUs at various locations in the network, data compression schemes, and sending only changes in the PDU information rather than the entire PDU. Multicast addressing schemes and protocols will be used to create and control groups where PDUs are only sent to members of that group. The multicast mechanisms are currently being developed and will be specified in the areas of communication architecture, network management, and simulation management."* [10]

You mentioned in the previous section that the RTI:

> *"… acts almost as part of the underlying operating system of the host computer. In fact, it can even be thought of as an addition to the operating system, extending the systems capability."*

However, that in it self is a problem. The use of the RTI poses a number of questions:

- How does an RTI work?
- Do they all work in a similar way?
- What is the benefit of using one RTI over another?
- We can use either Mäk's RTI [20] or the DMSO RTI [21] in the laboratory, but which is better?

Mäk claim that their RTI is optimised for real-time operations, and yet they state that:

> *"However, since the Mäk Real-time RTI does not implement all services, it is possible that it may not meet requirements for a particular federate."* [20]

This sounds very dangerous. As a developer, I want to know what is going on.

HLAman: There are a number of RTI implementations that one could use. At the present moment, the documentation of the internal workings of an RTI is difficult to come by.

In terms of performance, research is being done. Graffagnini [22] and Wuerfel and Olszewski [23] have consider what we mean by performance and have produced metrics. In addition, Wuerfel and Olszewski [23] have produced results using their metrics for the DMSO RTI 1.3v5. Oesterreich *et al.* [24] have developed an RTI evaluation tool and produced results for the DMSO RTI 1.3NG. Indeed, on the DMSO HLA web site [5] a tool set for benchmarking the performance of an RTI implementation can be downloaded for a variety of operating systems.

In addition, Pullen and Kakarlamudi [25], Fujimoto and Hoare [26] and Sjöström *et al.* [27] have investigated the performance of a number of RTI implementations.

There has been an on going debate recently on having an open-source policy for RTI technology [28]. This would allow developers to exchange ideas, develop new RTI implementations making improvements and optimisations.

To some extent, performance issues aside, the RTI implementation is immaterial. The RTI is another component within the federation. As such, it can be replaced without affecting the actual federates. As Kuhl *et al.* [8] state:

> *"… the [RTI] layer insulates the federate from changes in technology that may be reflected in the RTI, If the RTI must be modified to accommodate a new kind of network, the federate is unaffected."*

We saw that a federate only exposes to the outside world a defined interface, that is its SOM. The internal workings of the federate are completely hidden. In a similar way, the RTI also presents an interface to the federate via the Federate Ambassador and the RTIambassador. In doing so, the internal workings and state of the RTI is hidden.

Reuse

In this final section, our two developers discuss how systems developed using DIS and HLA-RTI can be re-used.

DISman: When using DIS, I can add my simulator into any exercise that is using the same version of DIS. The one potential interoperability difficulty is the non-standard enumerations, particularly for the entity types. However, we do have a reference document that suggests values that we could use [13]. In addition, we can exchange between the participants the list of enumerations and types prior to the exercise.

The problem with HLA-RTI is that for re-use the FOM must be the same.

HLAman: That is not strictly true. Kuhl *et al.* [8] state that:

> *"The FOM is the vocabulary of the data exchanged through the RTI for an execution of the federation"*

Thus, for a federate to be able to be re-used, the vocabulary of the FOM must contain the vocabulary of the federate. Thus we can grow the FOM to allow new federates into the federation, but still be able to make use of older federates.

It is the hierarchical nature of the classes in a federation object model that allow it to grow. We can derive new classes extending the object hierarchy to make use of new federates, but leave unaffected the older federates. This is one of the goals of HLA – to protect federates from change. As Kuhl et al. [8] state:

> *"… federates that were written to expect and use certain object and interaction classes can continue to use them even if the FOM is extended with subclasses not there originally."*

DISman: In this case the vocabulary of the new FOM must still contain the same *words* as required by the old federate. Thus, for example, an attribute called *position* must still be called *position*, and the co-ordinate system used, must still be the same. As you mentioned, the class hierarchy can be extended, but if it is changed dramatically, then to allow an old federate to use this new FOM, there may be significant code changes required. As an example, the IST HLA Gateway [29], was developed for the version 0.5 of the Real-Time Platform Reference FOM (RPR-FOM). Table 1 shows the object hierarchy for classes directly derived from the class *PhysicalEntity* as produced by the Object Model Development Tool [30].

Table 2 shows the object hierarchy from the same base class (*PhysicalEntity)* in version 1.0 of the RPR-FOM [31]. As we can see, there has been an extensive change in the object hierarchy and object names. Although version 0.5 of the RPR-FOM was written in its early stages of development, software written specification for this FOM would require significant changes to allow it to work with the later version.

So although, the federation object model may be extended, care is still required as the names of objects, attributes, interactions and parameters are not fixed. Nor are their types. For example, a position attribute may consist of three co-ordinates, x, y and z. One federate may use single precision 32-bit floating point values, whilst another may use 64-bit double precision values. Although these problems are not insurmountable, they need to be clearly identified and resolved.

Class 2	Class 3	Class 4	Class 5
PhysicalEntity	MilitaryEntity	MilitaryPlatformEntity	MilitaryAirLandPlatform
			MilitaryAmphibiousPlatform
			MilitaryLandPlatform
			MilitarySpacePlatform
			MilitarySeaSurfacePlatform
			MilitarySubmersiblePlatform
			MilitaryMultiDomainPlatform
		MunitionEntity	
		Soldier	
	CivilPlatform	CivilAirLandPlatform	
		CivilAmphibiousPlatform	
		CivilLandPlatform	
		CivilSpacePlatform	
		CivilSeaSurfacePlatform	
		CivilSubmersiblePlatform	
		CivilMultiDomainPlatform	
	Civilian		

Table 1: RPR-FOM 0.5 Object Hierarchy

Class2	Class3	Class4
PhysicalEntity	Platform	Aircraft
		AmphibiousVehicle
		GroundVehicle
		MultiDomainPlatform
		Spacecraft
		SubmersibleVessel
		SurfaceVessel
	Lifeform	Human
		NonHuman
	CulturalFeature	
	Expendables	
	Munition	
	Radio	
	Sensor	
	Supplies	

Table 2: RPR-FOM 1.0 Object Hierarchy

Conclusions

In this paper, we have made a number of comparisons between DIS and HLA-RTI in their use for real-time virtual simulation. We have seen, that there is the potential to improve DIS as it currently is. Some of these improvements may require considerable work such as the implementation of a DDM structure. However, the frequency of the much-criticised heart-beat Entity State PDUs can be readily reduced, thus decreasing the network bandwidth requirement.

For HLA-RTI, we have seen that its architecture eases the system development process and can ease system re-use. However, issues do need to be resolved. These include the availability of RTI implementations and the widespread knowledge of their workings. Additionally, although one of the goals of HLA is the ability of federates to be re-used, there are potential problems when using a future FOM. These problems need to be identified and resolved as early as possible in the federation development process.

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Author Biography

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NATO Long Term Scientific Study (LTSS/51)
on Human Behaviour Representation
(SAS-017)

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Human Behaviour Representation, Staff Level Decision Making

ABSTRACT:

NATO LTSS are held to give a forecast on technological developments in specific areas with their impact on military operations and to give recommendations for future research activities.
The paper will give an overview on the results of the LTSS for Human Behaviour Representation. This includes a definition of the term Human Behaviour Representation as used by the study team, an overview on the state-of-the-art, a discussion of applications in NATO, and the technological forecast. The recommendations for future research activities as a result of the LTSS symposium will close the paper.

Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

1. Introduction

Long Term Scientific Studies (LTSS) are conducted by the NATO Research and Technology Board (R&T Board). The purpose of these studies is to provide a report on technological implications to military operations in the next 10 to 15 years and to give research planners recommendations.

Human Behaviour Representation is a topic that is referenced in a number of applications like Decision Support Systems (DSS) in operational planning, the representation of specific cells in a Computer Assisted Exercise (CAX), closed simulation systems for analysis and acquisition purpose that can be used without the engagement of operational people. The adequate implementation and operational usefulness of such a representation will help to develop more cost-effective simulation systems and better decision support systems in the future.

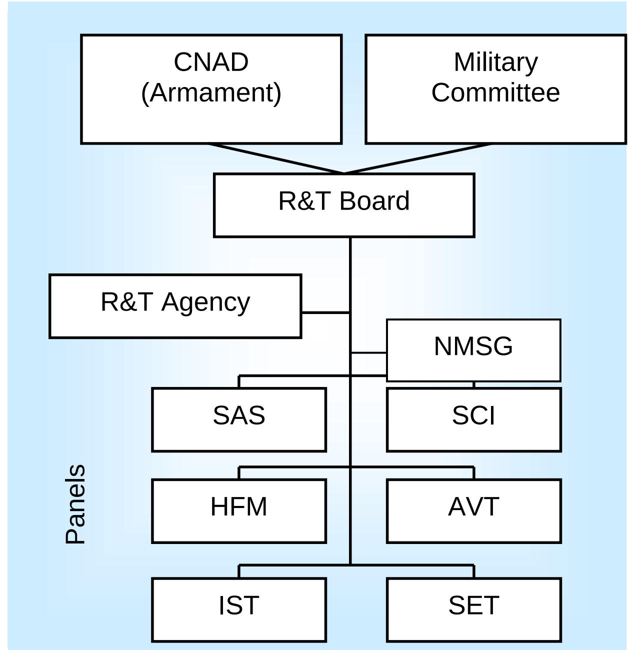
So the use of such tools is not limited to one specific application area. They could be used in the operational CCIS, as analysis tools, or in the support of Computer Assisted Exercises or in supporting the acquisition process of military systems. Therefore the LTSS will have a wide impact on any such military planning.

The research and development of the technologies needed for HBR is done at universities as well as by industry. But the main part of developing strategies to get the needed operational know-how and the means to implement this knowledge is left to research and development to be conducted by the military community itself being therefore a highly interdisciplinary task.

In Chapter 2 the purpose and study procedure of an LTSS is explained. A definition of Human Behaviour Representation as used by the study team will be given in Chapter 3. Chapter 4 discusses possible applications in NATO. The technology forecast of the identified technologies is shown in chapter 5 as roadmaps starting from the state-of-the-art to 10 to 15 years ahead. Chapter 6 summarizes the main recommendations given by the study team.

2. Long Term Scientific Study - Purpose And Study Procedure

Figure 1 shows the NATO Research and Technology organisation. The Research and Technology Board (R&T Board) reports to both the Conference of National Armaments Directors (CNAD) and the Military Committee. The R&T Agency supports the board in its work. The six panels and the NMSG are reporting to the board.



SAS Studies, Analysis, Simulation
IST Information Systems Technology
SCI Systems, Concepts and integration
AVT Applied Vehicles Technology
SET Sensors and Electronics Technology
HFM Human Factors and Medicine
NMSG NATO Modelling & Simulation Group

Figure 1: NATO R&T Organisation

The Technology Group "Studies Analysis and Simulation" (SAS) under the R&T Board conducts Long Term Scientific Studies (LTSS) to

- provide a report for the use by NATO and national authorities on technological implications to military operations in the next ten to fifteen years and to
- provide research planners with recommendations.

This means that technologies needed for a specific military task (e.g. for maritime operations or Computer generated Forces) are identified and their development in the future is evaluated.

On the other hand, military requirements for the future are identified and the application of technological.

3. Human Behaviour Representation (HBR) - Definition

"Human Behaviour Representation" is used as a generic term to refer to computer representations of human behaviour in simulations. In the Final Report of the study “Human Behaviour” is defined in following way:

Human behaviour (B) is a purposive reaction of a human being (P) to an idiosyncratic meaningful situation (S).

Formally expressed: B= f (P,S). In words: the observed variability in behaviour is attributable to differences in the person’s characteristics, to differences in the situation and/or to the interplay of both.

- Mathematically spoken: the variation in the measured behaviour can be explained by the variation in P, the variation in S and interaction between P and S (measurement error not taken into account). This definition implies that human behaviour:
- Is a change from one state into another state (bodily and/or mentally);
- is always goal-oriented (but not necessary in a one to one relation)
- is a reaction to an external observable stimulus or to an internal covert stimulus,
- has three interrelated components: a cognitive, a psycho-motor and a socio-affective component
- is an integration of several physiological and mental processes
- is individualised because each individual interprets the objective characteristics of the situation.
- Is neither necessary “rationale” nor the most appropriate reaction under given circumstances.

4. Future Military Environment and Applications of HBR

NATO’s first mission is still Article 5 Operations. So the use of HBR should be considered in this environment to support military applications. Besides Article 5 Operations NATO has to conduct Crisis Response Operations. Especially in applications to support these operations HBR will play a major role.

Application areas for HBR are:

- Instruction, Training, Exercise
- Defence Planning
- Support to Operations
- Akqusition

4.1 Instruction, Training and Exercises

The goal of instruction and training is to learn new skills and improve specific skills in individuals and teams. In order to support these tasks, it is necessary to develop a model of the subject of the instruction and training (the trainee or group), a model of the instructor and models of the inanimate systems, other human or human-operated platforms that the trainee(s) interact with. The model of the instructor includes evaluation or performance measurement models and models of the various strategies that can be applied to achieve the knowledge transfer objectives. All these models are required for any form of instruction and training. In order to automate these models, they need to be made explicit and it is necessary to develop a suitable framework for HBR.

Given the growing need to provide effective training, the limited resources available to achieve the knowledge transfer objectives and the increasing complexity of military tasks, the need for automated formal representations of human behaviour is pressing. The availability of the various models described above is essential to support the concept of providing instruction and training for individuals and for teams on an any time, anywhere, on demand basis. It will also allow the same training standard to be achieved in less time through a better evaluation and feedback capability and through the application of more diverse scenarios.

An improved level of training will also benefit the effectiveness of live training, since individuals and teams, trained in simulated environments, will start with an increased skill level. Considerable associated side benefits are the reduced impact on the environment and the increased effectiveness of deploying costly resources. Live exercises will actually become more cost-effective because richer scenarios containing more elements of the environment can be addressed in terms of personnel, artificial and natural components.

Finally, the availability of an automated instruction and training environment that includes effective models of the trainee(s), the instructor and the elements of the real world that they interact with will allow continuous training to take place. It would provide every individual and team performing a military task to benefit from a virtual instructor that is continuously monitoring performance and that can provide a just-in-time rehearsal capability.

Exercises are aimed at maintaining and applying acquired skills. They also serve to generalise knowledge and increase the ability of individuals and teams to select and apply suitable knowledge. Exercises are key to the development of knowledge concerning the application of skills, also referred to as meta-knowledge. They typically require substantial interaction with other teams and the deployment of large numbers of personnel acting as exercise facilitators in the form of directing and response cell staff (representing opposing, neutral and friendly forces NGOs, PVO and others). In exercises, the emphasis shifts from instruction and training to a form of peer-level coaching.

The availability of automated representations of the behaviour of the individuals and teams that the exercising personnel interact with, will allow exercise settings to be composed in a more flexible, modular manner. It will also allow the environment to behave overall in a more consistent manner by removing biases due to level of training and experience of augmentation personnel. Given that the representations have been developed for interoperability and scalability, variable levels of granularity could be mixed to provide the appropriate level of information during the exercises.

The consistent behaviour of automated representations and their ability to record actions and information flow will improve the ability to provide feedback resulting in an improved capability for after-action review.

Finally, automated representations of human behaviour will result in a reduction in staffing levels for response cells, other forces and directing staff functions. It will also allow the simulation environment to be used for other purposes, e.g., acquisition and decision support. It must also be mentioned that a simulated environment containing these representations of human behaviour will enable the exercising of situations that cannot be created in a live exercising environment.

4.2 Defence Planning

Defence Planning in NATO is the identification of future requirements to address anticipated missions, five to fifteen years in the future. Defence Planning identifies required capabilities to solve future problems. Defence Planning is subdivided into the following disciplines: Force Planning, Armament Planning, Reinforcement Mobility Planning, Logistics Planning, Nuclear Planning, Infrastructure Planning, Stockpile Planning, Civil Emergency Planning, and Command Information System Planning. Of these areas, Force Planning and Command Information System Planning are the main areas that require HBR research.

The challenge facing Force Planners is predicting the geopolitical changes that will occur in and beyond NATO's Area Of Responsibility (AOR) and defining the forces that will be required to address future operations. Important issues are, should NATO continue to focus on conventional military operations or should it prepare for cyber warfare? How many peacekeeping, peace enforcement, and humanitarian missions will NATO conduct simultaneously? How far a field will they be? The working group was not aware of any models that could provide defence planners insight into evolution of geopolitical change and which would them help plan the future force structure of NATO.

The challenge facing Command Information System Planners is defining command and control systems for the wide range of contingencies operations that NATO may undertake in the future (to include potential Article 5 and non-Article 5 missions (Crisis Response Operations)). Such missions may include non-NATO military units and may occur outside NATO's historical AOR. In addition, for CRO missions, NATO command and control echelons will need interfaces with non-governmental organizations and other entities (such as the U.N.). Command Information System Planners need sophisticated organizational modelling capabilities that will enable them to quickly investigate alternative command and control structures. Such models must be sensitive to cultural differences and be capable of analysing NATO and non-NATO organizations, and their interactions.

4.3 Support to Operations

NATO anticipates that in the future the pace of decision-making will have to be increased in order to allow NATO forces to plan and conduct operations within their opponents decision-making cycle (i.e., before the opposing side can respond in an organised manner). Further, it is expected that the amount of information available, in real-time, will increase dramatically and that decision-support tools will be needed throughout the NATO command hierarchy in order to process this increased amount of information. In addition, a recent trend within NATO has been the integration of simulation with C3I system, and the real-time use of simulation to support operational decision-making. HBR will play a role in meeting future C3I challenges by providing support for information integration and course of action generation, as well as supporting advanced simulation-based tools.

To support the military user intelligent interface agents are needed that resides on a computer where it acts both as a personal assistant proactively tracking information and alerting users to problems and opportunities and as a portal to diverse C3I systems, providing the user with one interface with which to perform their daily duties. In addition, interface agents may someday function as coaches, providing the novice user guidance on how to perform a specific task and explaining the implications of various proposed courses of action.

In addition, HBR will play a role within simulation systems, where advanced HBR models will enhance contingency planning, intelligence assessment, force generation and deployment planning, sustainment of operations, and current operations. Specifically, it is expected that inferencing and reasoning techniques derived from HBR research will improve many aspects of NATO operations when incorporated into decision-aids.

4.4 Acquisition

There is a great need in the design of future systems to increase mission capability while reducing manpower requirements and overall cost. The challenge is to concurrently design new organisations, equipment, and human tasks in a radically different context. This is a different problem from engineering enhancements of legacy systems, which is the historical norm.

In this critical problem area, models of organizations and teams are required in the early concept stages to define possible organizational structure and designs, and simulate the effectiveness of candidate structures in planned battle spaces.

As design proceeds, team models are needed support concurrent engineering of human roles and tasking (on the one hand) and design of equipment and automation that the acquisitions community will use (on the other hand).

Given the lack of analogies and historical data provided by legacy-based design approaches, team and organizational models provide the only viable approach to quantifying and evaluating the organizational, team, and task-teamwork design of radically different future systems. A key missing capability (today) is finding a way to allocate roles in a quick way and translate such design oriented models and to a simulatable representation that can interact with external simulations (e.g. synthetic battle spaces). Team-organizational models also provide a vehicle for coordination with hardware/software design portions of the design team. They allow equipment designers to evaluate the human impact of designs and design to human needs, from trainability and usability to planning for manpower requirements and recruiting.

5. Emerging Research and Technology

5.1 Individual Behaviour Modelling

The modelling of cognitive and mental Individual Human Behaviour made big progress with programs done in the last 20 years. A broad range of techniques have been developed and are in use. Nevertheless there are shortcomings in modelling the effects of socio-affective factors. These modelling techniques are needed for the application of HBR in Crisis Response Operations (CRO).

To represent human behaviour in a military valid and possible exhaustive way, it is necessary to work within a defined common problem space and then to analyse mission types within this space in order to derive relevant military tasks leading to a satisfactory execution of that mission. To focus on the modelling of relevant behaviour, the analysis of the mission types should be driven by a need analysis. In a second step, a particular job should be described in terms of a limited set of generic behaviours. Finally, this job description is to be seen as a framework for a learning and teaching tool.

A complete model of individual human behaviour must always contain the three domains of behaviour – cognitive behaviour, motor behaviour, and socio-affective behaviour - and take their interactions into account in the execution of a military task within the defined problem space. Because the socio-affective aspects of behaviour as moderators in overall behaviour are not well understood and because the relationships between socio-affective behaviour and cognitive and motor behaviour have only been addressed in isolated and specific circumstances, an effort must be made in the study of socio-affective behaviour.

A taxonomy of generic tasks expressed in terms of individual behaviour within the military problem space is necessary and includes the following: planning, intelligence, situation assessment (Command and Control), manoeuvring, target acquisition and weapon delivery, maintaining mobility and survivability, after action review. The priorities of these military behaviour tasks were determined to be the following: (1) Planning, (2) Intelligence and Situation Assessment, and (3) After Action Review. The criteria in determining the priorities were (1) feasibility of determining a solution in terms of technology and tools available to apply to the task, (2) time required to implement an approach, and (3) importance for the military application (decision maker) (see 5.1.8).

Related to the domains of application, the complexity within human behaviour modelling goes from operations support, through exercising then to training/instruction because there are in each step of this chain more components necessary to be represented in the environment. A complete model, suited for instruction and training, must contain a representation of the behaviour of the three players: instructors, student, trainee and third persons. Moreover, it is necessary, but difficult, to implement an intelligent tutoring system (ITS) and an adaptive aptitude-treatment interaction system (ATI), which is necessary as one moves from the support operations to the instruction application. For example, once a tool for operations support to use as an aid has been developed, one must add a monitoring/observing capability to move into the exercise application field, and then finally, a tutorial capability must be added to operate in the training/instruction application area.

To meet fully the requirements of the NATO Modelling and Simulation Master Plan, the highest priorities have been given to both planning and intelligence/situation assessment (Command and Control) to deal with the issue of information overload and eventually lack of relevant information. These tools must allow also for elaboration and evaluation of alternate plans and alternate courses of action. In the area of instruction and training, an intelligent tutorial system is required (saves personnel, easier composition of the training, broad application, allows interaction, provide automated after action review, reusable, etc.). The same arguments hold for after action review across other application domains; an intelligent observer is necessary to take full advantage in reuse of lessons learned and tutor when the application or exercise is completed.

The major advantage of automated after action review is the ability to keep track of the behaviour of the trainee from the beginning of the instruction/exercise to the end of the mission and then allow for the review of the actions as compared to an optimal solution. The major necessity for automated after action review is derived from the situation that the observer/action reviewer is not able to deal with the entire information space and then recall for later review and evaluation. This data collection allows for the capability to address the most frequently occurring issues for the training so that the reviewer may be focused on the issues that require the most attention for review and possible remediation.

5.2 Team, Group and Organization modelling

Formal computational modelling of military teams, groups and organizations is currently not well developed. The fields of social and industrial/organizational psychology have yielded a number of useful concepts that can be exploited for military application. However, the critical shortfalls are that these concepts for the most part are informal rather than computational, and focused on civilian rather than military social entities.

Current military efforts in the fields of team, group and organisational modelling are not coordinated across agencies and NATO countries. This lack of coordination extends both to the domain of modelling and to that of database development and archiving.

A significant improvement in a priori predictive capabilities and force readiness is possible through improved HBR of teams and organizations. This point is driven home in the examples provided above.

No program to achieve needed improvements in modelling teams and organizations exists within any NATO nation at the present time for application in military simulation for instruction, training, and exercise, acquisition, support to operations and defence planning.

5.3 Process

The current state of the practice for developing HBR is more of an art than a science. Available models are mainly R&D efforts, built for a particular application, or with a particular research idea in mind. The implications of this situation are that models have limited generalisability beyond their development environments. This is unfortunate, since the need for human behaviour within simulations is increasing. To promote reusability of previous efforts and to encourage cost-effective development, a more structured approach to human behaviour modelling is advocated. Following conclusions related to HBR development focus on knowledge acquisition, validation, composability and interoperability.

Current knowledge acquisition techniques are time- and skill-intensive. On-going developments in cognitive architectures are emerging which may provide guidance to the knowledge acquisition process.

Nearly no program to investigate validation techniques for specifically representing human behaviour exists within any NATO nation.

No agreed upon framework exists to guide research in human behaviour composability.

Considerable work remains to be accomplished within the HBR community to promote interoperability among models representing human behaviour. A framework to foster interoperability is missing.

6. Recommendations

The co-ordination of R&D programs of the different NATO nations would help to get better results. This co-ordination could be organised using existing procedures and organisations in NATO (e.g. Research and Technology Board and other NATO Agencies like NC3A). Bilateral or multilateral research and development programmes which support the development and application of HBR will reduce costs, and achieve better results with greater efficiency.

Recommendations must cover a breadth of topics ranging from demonstration programs to test newly available technologies and interoperability/ composability issues over studies to establish the foundations for larger multinational research efforts to long-term research programs of a more fundamental nature.

Demonstration programs are intended to show the potential of already available methodology and technology to the user and on the other hand to bring the developer and researcher community in contact with the user to know more about the specific needs and requirements from the operational side. If such demonstration programs are done in an open testbed that allows to look for interoperability and composability issues this approach will help to shorten the time to make such new developments operational and to save money and resources through reuse.

Besides these demonstration programs on the basis of available technology the conclusions driven showed that in all areas for HBR is still a need for basic scientific research that is not done by the commercial community. Even if these programs will need a longer time to lead to operational applicable system, the benefits make it worthwhile to start now.

Following recommendations with highest priority were derived from the discussions:

- Establish an NATO RTO Exploratory Team to build up a virtual institute for research on human behaviour modelling *(SAS-Panel, HFM-Panel, IST-Panel, NMSG)*

- Establish a NATO RTO Specialist Team on a research plan for team, group and organizational modelling research *(HFM-Panel and SAS-Panel)*

- Establish a testbed for demonstrating and studying composability/ interoperability issues related to modelling individuals, teams, groups and organizations *(Multinational with participation by SAS-Panel, NMSG, NC3A, NATO Strategic Commands)*

- Establish a NATO RTO Task Group to characterize best practice in HBR validation (build on DMSO Guide to Recommended Practice for VV&A) *(SAS-Panel, NMSG)*

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Synthetic Environments - The Met. Office Approach

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Introduction

Weather is critical to all military operations, whether on sea, in the air, or on land. While equipment development continually strives for an all-weather capability, and ideally for weather independence, these advances more often lead to a capability for operations in more marginal conditions, increasing, rather than decreasing, the need for weather guidance. For this reason, the paper has been structured to first describe some of the critical influences of weather on military operations, then to describe current Met. Office work in synthetic environments, and then to look at some other related requirements for weather information.

The importance of weather to military operations

Military requirements can be divided into a small number of areas, most of which apply equally to all three services. The first requirement is to support military transport, for reconnaisance, attack and support, by land, sea and air. These operations are sensitive to the condition of the land and sea surfaces and to atmospheric conditions at flight levels. The second requirement is to support target acquisition, typically depending on remote sensing of the target by acoustic, visible, infra-red or radar sensors. For this, the emission and reflection characteristics of the target, together with the propagation characteristics of the intervening medium, either atmosphere or ocean, need to be known. There are also requirements for knowledge of the dispersion of contaminants in the atmosphere and ocean, and for prediction of the influence of the atmosphere on the trajectory of airborne munitions. The following examples illustrate some of the types of weather that impact on these operations.

Much of the weather sensitivity of modern forces arises in target acquisition. While sensors have improved greatly, visual contact with the target is still important. Figure 1 shows an early morning picture of a valley in hilly terrain under clear skies. Nocturnal cooling has resulted in fog formation, completely hiding the valley floor from view. This fog will clear as the sun rises, generating upward motion on the valley sides. The fog is impenetrable at visible and infra-red wavelengths. It is transparent to radar, though refraction may occur in rays that propagate through the top of the fog at a shallow angle.

Fig. 1 Early morning fog hides surface features

Paper presented at the RTO NMSG Conference on “The Second NATO Modelling and Simulation Conference”, held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

Detection of surface targets depends not only on transmission of information to sensors, but also on the contrast of the target against its background. In visible wavelengths this depends, amongst other things, on its solar illumination. In clear skies and flat terrain this can be calculated relatively simply. However, in the example shown in figure 2, there are difficulties in calculating contrast to the right of the hill top. Due to its steepness, parts of the slope are in the direct shadow of the hill. However, to complicate matters, airflow over the hill has generated a capping cloud, which is stationary over the hill. This cloud substantially extends the area of shadow, and because it is stationary, the effect is much more significant that might be expected from the overall cloud cover.

Fig. 2 Cap cloud shadow reduces contrast

The presence of cloud has a direct effect on many airborne operations as a result not only of target acquisition difficulties, but also from icing and turbulence. While extensive cloud sheets are relatively easy to forecast and describe, the more broken structure of convective cloud elements poses much greater problems. Such cloud often forms into well defined structures, depending on the underlying topography or on local forcing arising from the structure of the large scale wind field. In the visible satellite image of England, Wales and Ireland shown in figure 3, some of these structures can be seen. Over land the shower clouds are mainly forced by topography, developing over the west-facing peninsulas and becoming broader and deeper (and probably producing more rain) as they move northeast in the prevailing wind. Note, however, that a cloud feature approaching Ireland and Southwest England has quite different orientation and probably results from a convergence line, or trough, in the large scale flow. As this moves onto land, the two forcing mechanisms will interact, possibly resulting in thunderstorm development along one or more of the pre-existing lines.

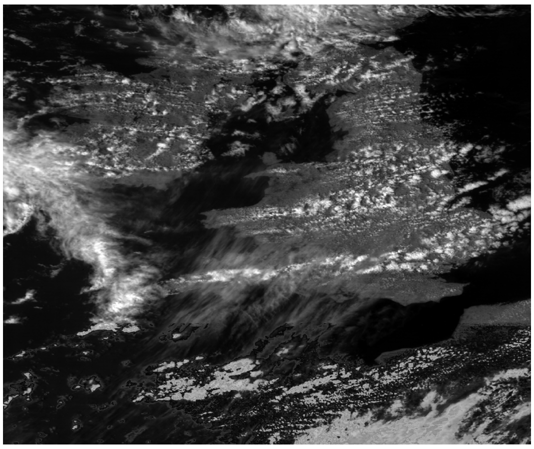


Fig. 3 Organisation of cloud streets over the UK

Precipitation is of particular importance to ground operations, although extensive flooding can dramatically alter the appearance of terrain and discharge of swollen rivers into the sea creates severe difficulties in coastal naval operations. The ability to move vehicles across terrain depends on the trafficability of the soil, which itself is highly dependent on the moisture content. After heavy rain, the surface layers of the soil can be deformed into a liquid sludge by the passage of heavy vehicles. Particularly in mountainous areas, small streams may swell into torrents, and rivers may spread across flood plains following a severe thunderstorm, an extended period of steady rain, or a sudden increase of temperature leading to snow melt. Figure 4 illustrates the possible consequences.

Fig. 4 Surface features change after heavy rain

Finally, the characteristics of the atmospheric boundary layer determine the dispersion of airborne pollutants on the battlefield. Atmospheric stability and wind shear determine the depth to which smoke and gas will mix and hence the ground level concentration. The wind direction and speed determine the areas affected. As well as predicting contamination areas and doses for toxic materials, such information is also needed to determine effects of smoke on target acquisition in the presence of fires and also the effectiveness of smokescreens. In Figure 5, the influence of a major waste fire on visibility is illustrated, with clear conditions in the upwind direction. In the downwind direction note the gradual clearance at ground level as the plume rises.

Fig. 5 Smoke dispersion depends on wind & stability

Creating a weather simulation

Simulation and prediction of weather require the same techniques and tools, though they may be applied in different ways. Prediction of weather is the primary function of the Met. Office and current techniques have been developed over the century and a half of its existence. The behaviour of the atmosphere is controlled, at the highest level, by the spinning of the earth. For this reason, any prediction or simulation must start with the largest scales and fit smaller scales within them. For weather prediction, the result is a cascade of forecasting tools, starting with assimilation of observations into a global Numerical Weather Prediction Model (NWP) and ending with manual adjustment of the detailed weather for a specific location. When applied to creation of a synthetic weather environment, we arrive at the following process:

Select past weather event with required characteristics from glocal archive:
matching season, climatic regime & synoptic type

↓

Interactively adjust large scale characteristics
to match required synoptic situation

↓

Fine scale simulation using mesoscale NWP model
with specified topographic characteristics

↓

Make final adjustments:
automated techniques to incorporate fine scale topography;
interactive techniques for precipitation, fog, cloud etc.

↓

Generate operational guidance using TDAs etc

The first step replaces global data assimilation and prediction in the forecasting process, taking advantage of the existence of extensive archives of past NWP analyses and predictions. The past event may be selected manually, as has been the usual practice for support to exercises, or it may be selected randomly within constraints. At this stage, the atmosphere is represented at a resolution of 50-100km.

The second step uses the Met. Office's On Screen Field Modification (OSFM) technique to make consistent adjustments to the full dynamical structure of the simulated atmosphere. This is a manual procedure, and enables the simulation director to tune the weather situation to meet the needs of the exercise. Interaction is normally via modifications to the mean sea level pressure field as shown in figure 6. Here the director has specified that the low pressure centre to the west of the UK should be moved forward and deepened in order to create a more intense storm. For some purposes, this level of detail is sufficient. Indeed, the weather simulation system provided by the Met. Office for STOW 1998 was based on these first two steps. However, considerable further detail can be obtained using other prediction tools, as described below.

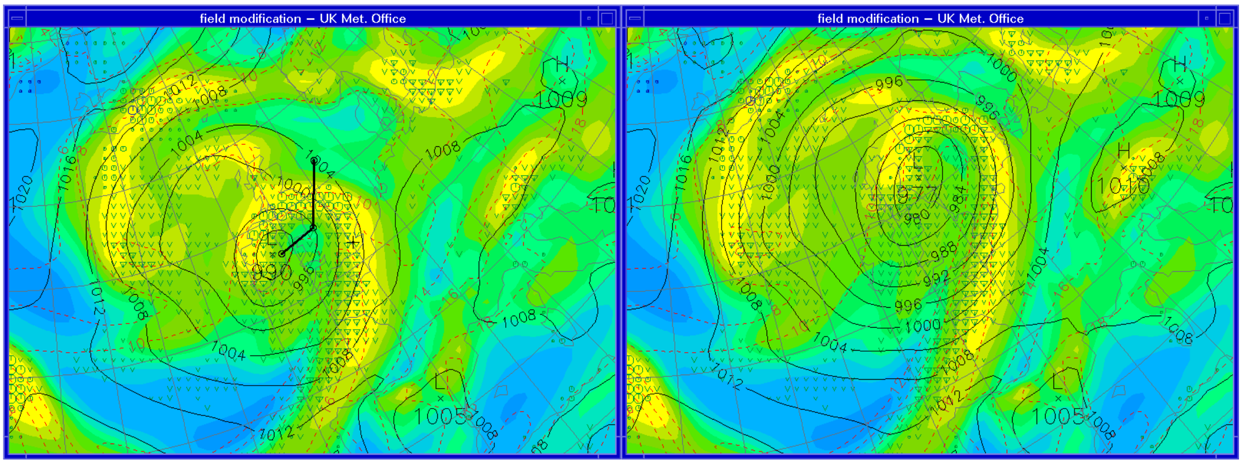


Fig. 6 The OSFM procedure moves and deepens the representation of an Atlantic depression approaching the UK.

In the third step, the influence of the synthetic topography can be incorporated, and the level of detail increased to a resolution of about 10km. The interface between the global and the mesoscale NWP models includes adjustment for changes in the topographic representation arising from the change of resolution. This mechanism can equally be used to make more radical changes such as growing a new island in the North Atlantic. It cannot be applied to simulate changes at the continental scale, for instance removing or creating a mountain range like the Alps but it produces very realistic effects for features on the scale of the British Isles. For best results, a spin-up period of about 12 hours is required before the start of the exercise. This step requires substantial computing power, available only on a super-computer, and so must be performed once, ahead of the exercise. The results are physically consistent atmospheric conditions which follow the diurnal cycle of daytime heating and night time cooling on land surfaces, and the resulting weather features such as sea-breezes, afternoon thunderstorms, nocturnal frost and fog etc.

In the fourth step, the final detail of conditions in selected areas of the battlespace is specified. This can be done automatically, using fine scale adjustments to the topography at a resolution of a few kilometres, or it can be done manually, adjusting individual elements such as rain rate or visibility to match the exercise requirements. Some of the automated techniques are currently implemented in the Met. Office's Nimrod system for very short range forecasting in the UK, and are being further developed to support battlespace forecasting using CMetS (Computerised Meteorological System). The procedures used in this step are quick and require modest computer power, and so could be carried out during the exercise, responding in real time to the requirements of the exercise director. The output of this step is the final four-dimensional description of the atmospheric structure and evolution during the exercise.

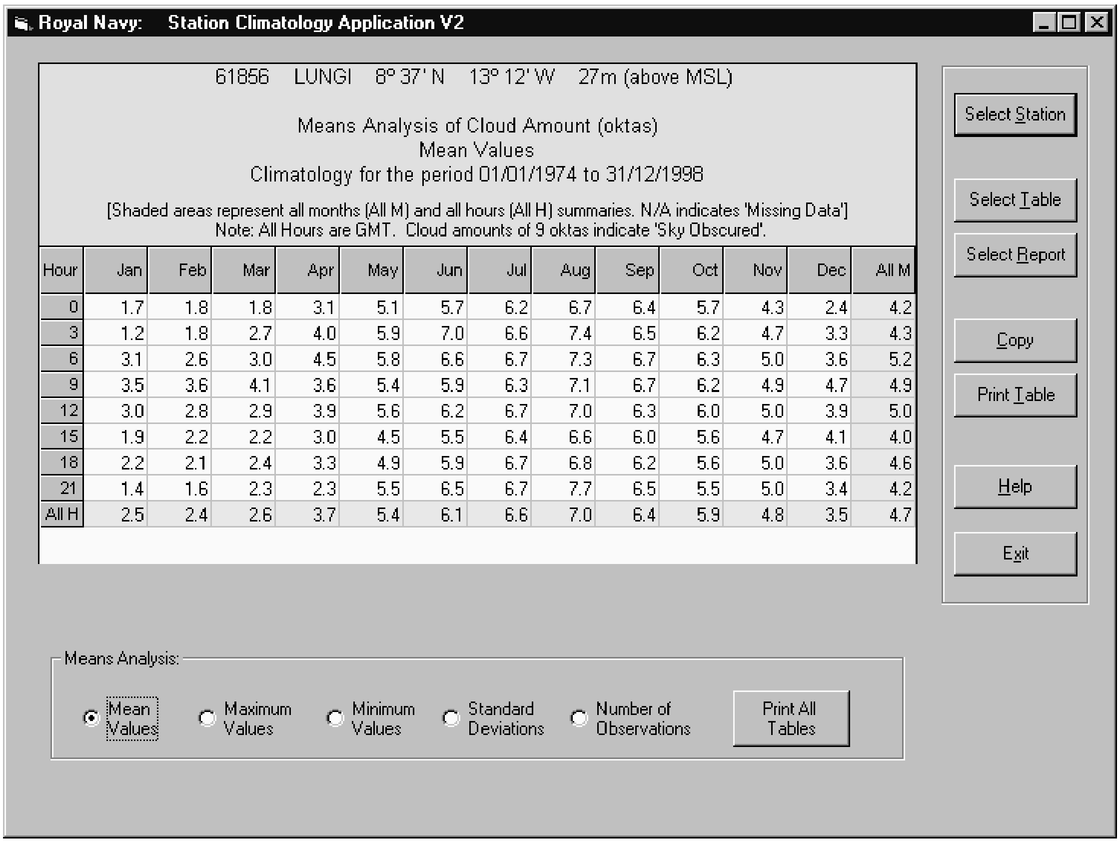
The fifth step converts the meteorological conditions into operational parameters. This includes some functions which may be performed on the meteorological system, such as calculation of illumination levels for NVG or infra-red visibility for target sensing, and others that will be performed elsewhere, such as NBC calculations and artillery targetting.

As described earlier, the capabilities described above are all available as by-products of the Met. Office's weather prediction services. In the past, requirements for synthetic environment support have been met by piecing together the relevant components as required. However, in recognition of the growing importance of this field, the Met. Office is in the process of establishing a more permanent capability. Initially, this is taking the form of a demonstrator based on an updated version of the system provided to STOW. Subsequently it will be expanded to incorporate the remaining steps in the procedure outlined above.

The procedure described above implies an unrealistic level of certainty in the simulation process. This is not a problem if the goal is to create a single scenario for an exercise. However, many of the prediction techniques themselves are capable of generating estimates of the uncertainty of the result. Increasingly weather prediction is adopting the language of probability for its more detailed predictions. While a single decision is needed at the end of the process, there are many aspects of military planning for which a risk assessment process incorporating quantitative estimates of weather probability, could be beneficial. Such procedures will ultimately need to feed back into exercises and synthetic data creation. In addition, since the weather forecast, itself, is part of the exercise, its errors should also be included. Errors in manual weather forecasts can easily be simulated using duplicate forecasting teams. For the automated component, more sophisticated techniques are required, using multiple NWP forecast runs, based on small modifications to the initial conditions. The procedure outlined above could easily be extended to incorporate this approach.

Other Simulation Requirements for Weather Information

Requirements of simulators are not always best met by creating data in the way described above. Indeed, for many purposes requiring conditions only at one point, records of actual weather conditions provide the ideal data source. This is especially true for simulation in support of equipment design and procurement, and user training, for which information such as temperature range, maximum wind, occurrence of heavy rain or snow etc is critical. In this area, too, new techniques are being applied to enable easier access to the Met. Office's databanks. For access to routine meteorological observations, a PC application is being prepared for distribution on CD, which will carry a wide range of information, a sample of which is shown in figure 7, in the form currently being tested by the Royal Navy. This version carries three-hourly observations of pressure, wind, temperature, humidity, cloud and significant weather for land stations, but it is planned to extend it to include marine and upper air data, and to use the synthetic modelling approach to provide information in areas for which reliable observations are not available.



Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All M
0	1.7	1.8	1.8	3.1	5.1	5.7	6.2	6.7	6.4	5.7	4.3	2.4	4.2
3	1.2	1.8	2.7	4.0	5.9	7.0	6.6	7.4	6.5	6.2	4.7	3.3	4.3
6	3.1	2.6	3.0	4.5	5.8	6.6	6.7	7.3	6.7	6.3	5.0	3.6	5.2
9	3.5	3.6	4.1	3.6	5.4	5.9	6.3	7.1	6.7	6.2	4.9	4.7	4.9
12	3.0	2.8	2.9	3.9	5.6	6.2	6.7	7.0	6.3	6.0	5.0	3.9	5.0
15	1.9	2.2	2.2	3.0	4.5	5.5	6.4	6.6	6.0	5.6	4.7	4.1	4.0
18	2.2	2.1	2.4	3.3	4.9	5.9	6.7	6.8	6.2	5.6	5.0	3.6	4.6
21	1.4	1.6	2.3	2.3	5.5	6.5	6.7	7.7	6.5	5.5	5.0	3.4	4.2
All H	2.5	2.4	2.6	3.7	5.4	6.1	6.6	7.0	6.4	5.9	4.8	3.5	4.7

Fig. 7 Example of a climate data presentation for Freetown Airport

For more detailed simulation, application of Met. Office research records may also be valuable. These have been obtained using the C130 flying laboratory, kite balloons and specialised surface equipment, for both remote sensing and in situ measurement. An example of the level of detail available is shown in figure 8, obtained from the Met. Research Flight C-130. The two plots show temperature and cloud liquid water content data at one-second intervals through the flight. At the temperatures recorded in this flight, any liquid water could produce icing on an appropriate surface.

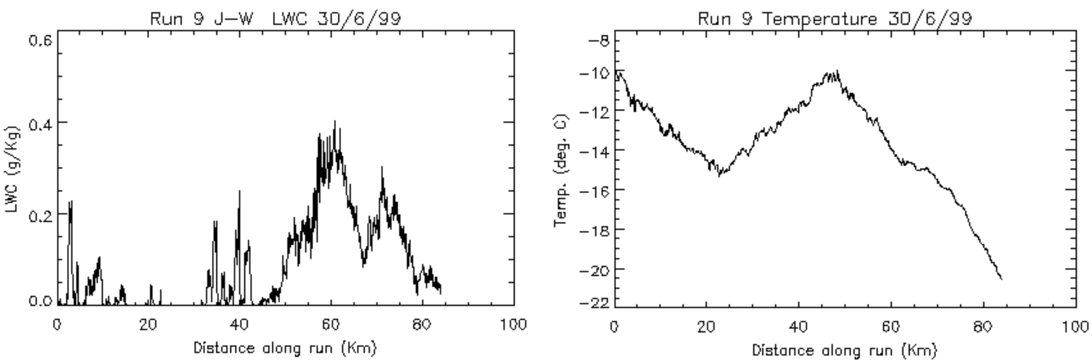


Fig. 8 Liquid Water Content (LWC), in g of water per kg of air, & temperature in ^{o}C recorded by the MRF C-130 aircraft

Use of such data will require close liaison between simulator designers and meteorological scientists, especially as simulators increasingly adopt virtual reality technology.

Summary

The weather has a strong influence on military operations and is likely to become an increasingly important component of operational decision making as increased weather capability is built into battle systems.

Based on its operational weather prediction capability, the Met. Office has contributed data to military exercises on many occasions in the past. This capability is currently being assembled into a PC-based demonstator, which will provide simulated weather information from continental scale down to details of battlespace weather at the kilometre scale.

Detailed information for use in simulators, for training and procurement support, is also available from Met. Office archives, including routine surface and upper air records, and research records from a variety of platforms.

Dynamic Terrain in the Synthetic Environment

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ABSTRACT

Simulation has become the primary solution for training U.S. Army soldiers in the use of real weapons systems. As such, the requirements for realism and greater fidelity are essential. An area lacking in achieving increased realism is the representation of Dynamic Terrain (real-time manipulation of the terrain). Command decisions and collective training by maneuver forces rely on terrain cues. The U.S. Army Simulation, Training and Instrumentation Command (STRICOM) has sponsored research in this area since the early 1990s. Early efforts were limited by technology and did not meet expectations. However, in December 1998 STRICOM awarded a contract to explore and develop an approach for a low cost, PC based solution for dynamic terrain that has demonstrated strong potential in resolving this long-standing need. A follow-on contract was awarded in December 1999 to implement the approach and demonstrate the feasibility and effectiveness of the concept. The results of this follow-on contract will be demonstrated at the Interservice/Industry Training Systems and Education Conference (I/ITSEC) in Orlando, Florida from 27-30 Nov 00. This paper describes the phase I and phase II efforts implementation of dynamic terrain into the synthetic environment using Distributed Interactive Simulation (DIS) and/or High Level Architecture (HLA) protocols, and a Synthetic Environment Data Representation and Interchange Specification (SEDRIS) Transmittal Format (STF) database.

INTRODUCTION

In a distributed simulation environment, the synthetic representation is one of the backbone elements that provide for a consistent battlefield. The synthetic environment is a representation of the physical world, within which all models of military systems interact. It includes both data and models that represent the physical characteristics of the environment, their effects on military systems, and the reciprocal impact of military systems on environmental variables (e.g. dust clouds from moving vehicles and spoil from combat engineering).

Real-time dynamic terrain has yet to be successfully represented in the synthetic environment. As simulations have become increasingly sophisticated and greater reliance on realism necessary in achieving combat proficiency through training, the presentation of real-time dynamic terrain presents one of the next challenges to the community. For the maneuver force and the combat support elements, the absence of dynamic terrain presents a significant deficiency in training objectives. For the maneuver force training in a collective environment, dynamic terrain provides cues that have affect on command and control of forces. Soil tracks provide indications of strength and direction of forces that have previously passed over the terrain. Freshly dug dirt may give an indication of some sort of obstacle being placed, such as a mine. A cleared lane through a minefield indicates area of safe passage. These are all terrain cues that provide valuable combat information. In today's synthetic environment, the capability to represent these cues in a real-time dynamic environment does not exist. Although there have been numerous research efforts, none have provided a reasonable solution that can be used for collective simulation-based training. With the wide assortment of simulators currently fielded in the various battle labs and simulation training facilities, a platform independent software solution for dynamic terrain is a growing need.

BACKGROUND

There have been numerous research efforts investigating dynamic terrain. The University of Central Florida (UCF), Institute of Simulation and Training (IST) demonstrated an early prototype of dynamic terrain utilizing a bulldozer plowing into a lake, causing water to flow and surround the bulldozer. The Defense Advanced Research Projects Agency (DARPA) Synthetic Theater of War (STOW) program developed the capability to communicate and emplace changes in terrain databases. However, results of both efforts were computationally intensive, requiring high-end computational platforms, and did not sufficiently satisfy real time requirements.

Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

THE PC COMPUTATIONAL AND GRAPHICAL CAPABILITY

The capability of PCs has increased significantly in recent years. Tasks that not long ago required high-end proprietary workstations can now be performed on low-cost platforms. A primary reason for the major advancements in PC technology can be attributed to the gaming and entertainment community. Because of the popularity of 3D games, graphics board vendors have been adding more and more features in a fierce competition where the fastest frame rate and best image quality wins. These new features include single-pass multi-texturing (which allows for realistic surface detail and lighting), full-screen sub pixel anti-aliasing, and hardware supported transformation and lighting to reduce the burden on the PC's CPU, giving it more time to perform other tasks such as artificial intelligence. The result of this competition is that fast high-quality graphics can now be generated using low-cost hardware and standard Application Programmer's Interfaces (APIs).

In military simulation, there is an ever-increasing demand to support more complexity in the visualization of synthetic environments. Providing higher fidelity not only requires faster graphics hardware with new features, but also efficient scene management tools that can take advantage of these advancements. The two main measures of a graphics accelerator's performance are polygon count and pixel fill rate. Polygon count is the number of triangles that can be sent to and rendered by the card in one second. Pixel fill is a measure of the number of pixels that can be rendered in one second. When trying to achieve high-speed, high-quality graphics, both measures are important. High polygon count allows for more complex models to be rendered, where pixel fill allows those polygons to be textured, lit, shaded, and anti-aliased. For realistic visual simulation, a graphics system must be capable of both high polygon count and pixel fill rate. In a dynamic terrain simulation, effects such as dust and visible differences in soil type can be used to increase the level of realism. Effects such as these that were difficult to produce even on high-end systems not long ago are now possible with PC technology. Figure 1 illustrates the level of realism that can be achieved.

Advancements in consumer-level graphics hardware have also brought about a more subtle advantage: real-time immediate-mode rendering is now feasible. In the past, most high-end graphic systems were based on retained-mode rendering. Retained-mode rendering is when objects are sent to the graphics system once at initialization and are stored (retained) there. Then when the object needs to be rendered, it doesn't have to be re-sent to the graphics system. This makes most graphic operations more efficient but has the disadvantage of making objects un-modifiable. This was not a problem in the past because there was never a requirement for a dynamic database. Dynamic terrain by its definition requires the ability to modify the visual database. With the increase in ability of PC-level graphic boards, immediate-mode rendering can now be used while still maintaining interactive frame rates. With immediate-mode rendering, objects are not stored in the graphics system, but are re-sent each time they are rendered. While this does make some operations less efficient, it allows objects to be modified in real-time from frame to frame. This is what makes dynamic terrain effects possible on a PC. Today, most graphics cards simultaneously support both retained and immediate mode rendering, so trade-offs can be made to achieve the desired result.

Figure 1.

According to Moore's law, CPU complexity and performance doubles every 18 months to two years. This means that the potential upgrade of hardware could have a two-fold performance increase on an existing application with little or no change in software. With this tremendous advance in chip development, the ability to perform real-time, PC based dynamic terrain has now become a reality. With the heavy competition in the gaming community, there is no end in sight to the growing list of features and performance available in PC graphics cards. For the simulation community, it means that by taking advantage of low-cost PC technology, features and capabilities previously limited will add to the value and realism of training and simulation systems.

Because of these significant increases in the computational performance of PC's over the recent years, tasks that previously required high-end proprietary workstations can now be performed on low-cost platforms. Capitalizing on these advances, STRICOM sponsored a Phase I Small Business Innovative Research (SBIR) contract to study an approach for developing a low cost, PC-based terrain solution. The technical objective required researching the feasibility of hosting a realistic, real-time and distributed dynamic terrain simulation on low cost PCs. A contract was awarded to Diamond Visionics Co.

(DVC). DVC not only completed a thorough research of the technical objective, but also demonstrated an early prototype. Based on the successful outcome of the phase I effort, a follow-on phase II contract was also awarded to DVC, requiring the completion of a prototype dynamic terrain implementation in an Image Generator (IG). The outcome of DVC's phase I contract and the objectives of the phase II contract are addressed in the following sections.

PHASE I - ANALYSIS OF TECHNOLOGY

The technical objective of the phase I effort required analyzing the feasibility of hosting a realistic, real-time and distributed dynamic terrain simulation on low cost PCs. Specific tasks of the phase I effort included:

1) Technical performance requirements analysis in a PC based system
2) Dynamic tessellation
3) Soil dynamics trade study
4) PC hardware and software architecture
5) Dynamic texture
6) HLA/DIS prototype study
7) SEDRIS Dynamic Terrain Extension Study
8) ModSAF Study
9) Phase I Option: Dynamic Terrain Technology Demonstration

Each of the tasks identified above are discussed in the following sections, however dynamic tessellation represents the most significant technical challenge in achieving a real-time dynamic terrain environment and is discussed in detail.

Technical Performance Requirements Analysis in a PC Based System. The objective of this task was to analyze and document, at a high level, the variability of requirements from all the possible users of a dynamic terrain implementation. A survey conducted with the user community resulted in the following conclusions:

1) Special effects such as explosions, spoil, battlefield clutter and animations were identified as priority items.
2) Intervisibility, weather and atmospheric effects were identified as significant attributes in achieving overall realism.
3) Terrain and soil characterization (for the surface and below) was identified as a primary concern.
4) PC IG performance should be a minimum of 30 Hz with the ability to page in a large terrain database.

The resultant requirements analysis established the focus for subsequent activities.

Dynamic Tessellation. Dynamic tessellation is the ability to deform terrain anywhere in the database in real-time without the need for predefined deformable areas. This was the most significant technological innovation identified as necessary in achieving real-time dynamic terrain. In determining the best way to proceed, two primary issues needed to be considered:

1) The ability to break up large polygons in the terrain database in real-time to provide finer deformation, thus achieving greater realism.
2) The ability to manipulate vertices in the terrain database in real-time to achieve terrain deformation.

Three approaches were analyzed as possible candidates: 1) Pre-Tessellation which requires the entire terrain database to be pre-tessellated. This approach was not considered feasible due to the significant memory requirement; 2) Pre-Tessellation of selected areas, which limits deformation to selected high interest areas. This approach did not provide the robustness necessary and would require foreknowledge of interest areas; and 3) Instantaneous Tessellation of the entire database. Although instantaneous tessellation of only selected portions of the database was investigated as an approach, the ability to prepare the entire database for tessellation was highly desirable to avoid the limitations associated with pre-selected areas of interest. Although more aggressive, this approach was selected due to the greater potential benefits.

Instantaneous dynamic tessellation allows a realistic deformation of terrain caused by interaction with a vehicle or other simulated object. Simplistically stated, additional polygons are created in the localized area where interaction takes place. This yields a smooth appearance of terrain movement as the vehicle deforms the terrain. In the initialized database, the terrain consists of many polygons of various shapes, sides, and sizes (figure 2).

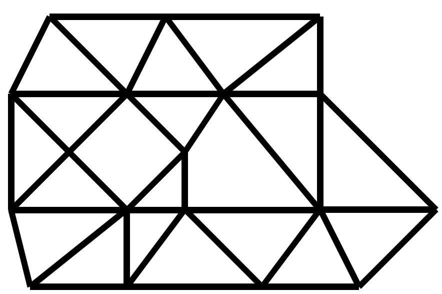

Figure 2.

A boundary area (square box) is established located around the intersection of the vehicle and terrain (figure 3) and this boundary area maintains relative position with the moving vehicle.

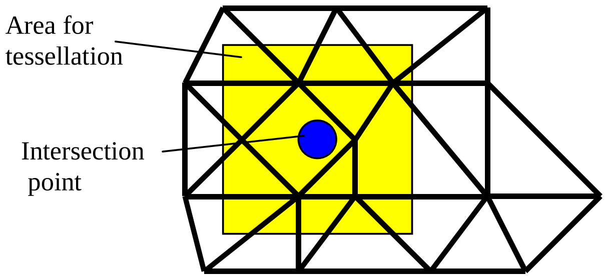

Figure 3.

All the polygons located within the boundary area are then triangulated (figure 4) and subsequently tessellated. This means that each original triangle is decomposed into four smaller triangles.

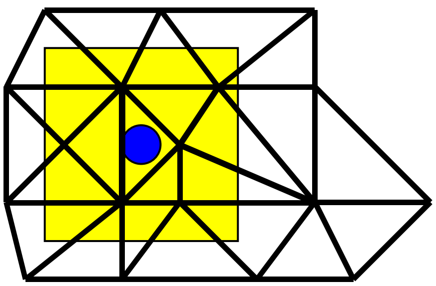

Figure 4.

This is done by connecting each segment midpoint to the midpoint of the other segments in the original triangle (figure 5).

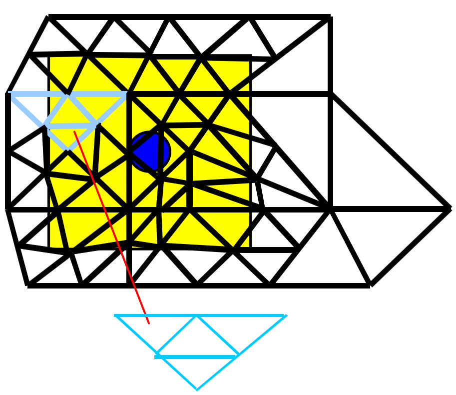

Figure 5.

Additional triangles represent a large increase in resolution in the localized area since there are now four triangles rendering the terrain area where there used to be one. Tessellation continues recursively until all triangles are sufficiently small to achieve the desired level of terrain resolution. Each triangle can be tessellated again if necessary for increased resolution. Actual terrain movement is accomplished by altering vertex positions, so a larger number of triangles will yield a smoother deformation.

However, tessellation poses a problem for the rendering database. New segments created by tessellation are not correlated with adjacent un-tessellated polygons. These new intersections are known as T-sections (figure 6).

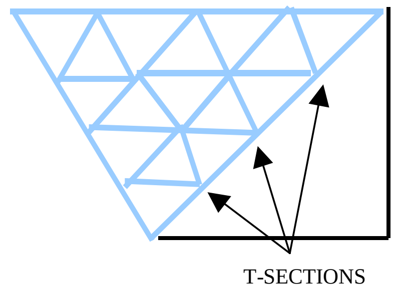

Figure 6.

Correlation problems need to be resolved or anomalies caused by small gaps along the edges will occur. In order to alleviate this problem, a transient layer is created to provide a smooth merging with non-tessellated polygons. First, the triangle with T-sections is checked to see if there is more than one T-section. If there is more than one, it is tessellated (figure 7).

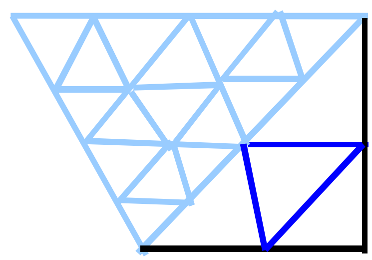

Figure 7.

The additional resultant triangles now only contain one T-section. The one T-section in each triangle is then connected to the vertex of the next outer polygon. The final T-sections are then removed by connecting to the vertex of the next outer polygon. This eliminates all the T-sections and completes the transient layer. The high-density polygons and the low-density polygons have now been connected seamlessly (figure 8).

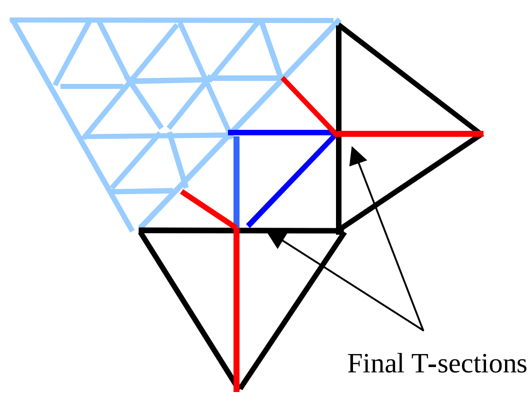

Figure 8.

T-sections must be tracked in the software. A map is utilized to associate T-sections with the triangles to which they belong. When a triangle is tessellated, on each of its sides a center point is generated. The three center points are used to construct sub-triangles. The program then maps the center points to their respective polygons. If the same point is stored to the map twice, the point will be removed from the map. After tessellation, only T-section points are left in the map. Their transient layer generation algorithms described above utilize these points.

As the vehicle moves away from the tessellated area, the terrain has been deformed and is no longer being adjusted. The original area of interest is no longer the current area of interest. If the vehicle stays away for a predetermined amount of time or moves a certain distance the terrain begins to de-tessellate. During de-tessellation, the extra triangles that were created are now deleted.

Soil Dynamics Trade Study. Four potential soil dynamic approaches were investigated and addressed from a feasibility of realism versus cost of implementation viewpoint. Actual implementation of soil dynamics will be developed in the phase II effort.

1) Physics-based Modeling. Used by IST at UCF. Although rendering an accurate portrayal, this approach is not ideal for a PC-based real-time solution as it is very complicated and extensive, necessitating significant performance overhead.
2) A simplified version of the above approach. This could provide the realism without the high fidelity modeling to recreate the precise physics of the problem.
3) Table-derived computational method. This approach would use tables generated from a physics-based soil model without using extensive run-time algorithms.
4) Hybrid Approach. A hybrid approach to soil modeling, which combines tabular data generated off line with real time computation.

Soil dynamics was not demonstrated during phase I. Instead, a rudimentary non-validated soil dynamic model was used.

PC Hardware and Software Architecture. This effort examined different computing platforms to determine the best way of solving dynamic terrain computational issues while maintaining a low cost solution. Factors such as different rendering techniques, database sizing, and graphic APIs were considered in the analysis. A variety of PC hardware and software architectures was examined with performance and flexibility in mind. For the hardware solution, high performance at a low cost was the goal. Speed and utility for the software was also a priority. Interestingly, current PC graphics hardware may be more suitable for dynamic terrain than some very high-end graphics systems. Many high-end systems load the database into very rigid structures in the hardware itself. This limits access to the database objects, making dynamic modification of terrain and other objects very difficult. Most modifications in these systems are done using simple replacement of one object for another to show changes. This limitation would make changing individual vertices impossible. PC graphics hardware, however, does not impose these restrictions. Rendering can be done in “immediate mode.” This means that for each frame, the visual software sends a complete update of the scene to the hardware. The inherent flexibility provided by even game-level consumer graphics hardware makes implementing dynamic terrain possible at a relatively low cost. For the software used in phase I, a set of C++ classes was implemented to form a complete database scene graph modeled closely after the OpenFlight format. In addition to the scene graph, an OpenFlight loader capable of populating the runtime structure from a standard OpenFlight file was implemented.

Dynamic Texture. This task assessed the feasibility of different dynamic texture approaches in achieving realism. Using dynamic texturing methods, many visually complex effects can be produced without excessive computational overhead. For this effort, the texture overlay method was utilized. This method provides very realistic effects, while using less memory from the graphic accelerator.

HLA/DIS Prototype Study. The task of developing the HLA/DIS compatible communication is critical to integrating with the Army’s networked simulators. Both ModSAF 5.0 and CCTT were studied as representative candidates that would benefit from dynamic terrain capabilities. Both systems have the capability to support real-time dynamic terrain objects simulation. The existing dynamic terrain applications are focused on creating effects. The protocol overhead for transmitting such effects is moderate. Based on these findings, a conclusion was reached that both DIS and HLA can support a dynamic terrain environment. The HLA will be more feasible due to its inherit flexibility. The ModSAF AFI Agile FOM Framework (AFF) provides a good model for future implementation. The phase I option contract provided a networked demonstration between multiple dynamic terrain enabled simulators.

SEDRIS Dynamic Terrain Extension Study. Dynamic terrain implementations must comply with SEDRIS, as this is becoming the emerging data interchange standard. The phase I study concluded that SEDRIS will readily support the demonstrated dynamic terrain implementation. SEDRIS primarily addresses the transmission of static synthetic environment objects. The evolution of SEDRIS Transmittal Format (STF) and SEDRIS WriteAPI has started addressing the object linking, incremental transmission, read-modify-write operation, unique and persistent object ID, and versioning control which all accommodate modeling and transmitting dynamic synthetic environment objects, in both real-time and off-line.

ModSAF Study. The ModSAF terrain functions were studied in detail and compared with CCTT SAF. ModSAF would support dynamic terrain in the form of DTSim and DT Agent. ModSAF currently supports discrete changes to the database. The current ModSAF dynamic terrain implementation, using Multi-State Object, deals with low-level details such as creating, modifying, and deleting polygons and features. This scheme will not effectively support the higher fidelity dynamic terrain, based on dynamic tessellation. By developing dynamic terrain in the ModSAF-compatible DTSim and DTAgent architecture, but using a more efficient "behavior-based" control mechanism, it is believed that higher fidelity can be supported. If OneSAF does not change ModSAF's Dynamic Terrain DTSim and DTAgent architecture, and that OneSAF will be SEDRIS compatible, the demonstrated dynamic terrain technology can be implemented with OneSAF.

Phase I Option: Dynamic Terrain Technology Demonstration. A demonstration was provided at the conclusion of the phase I effort representing the implementation of the tessellation technology previously discussed. The demonstration consisted of two dynamic terrain enabled simulators, maintaining an update rate of greater than 30 Hz operating on PCs. The instantaneous tessellation techniques and dynamic terrain deformation on the CCTT P1 terrain database was also successfully demonstrated.

PHASE II – PROTOTYPE DEVELOPMENT

Understanding that a PC-based real-time dynamic terrain capability was feasible as a result of the phase I activities, STRICOM awarded a phase II contract for further development of the prototype demonstrated in the phase I option, extending the capabilities. The phase II contract development is currently underway and will conclude in December 2000. Technical objectives of the phase II contract are:

1) Requirements Analysis
2) Dynamic Tessellation
3) Soil Dynamics
4) Dynamic Texture
5) LOD Management
6) Database Paging
7) Database Optimization
8) Special Effects
9) DIS/HLA Protocol Development
10) Dynamic Terrain Technology Demonstration

For the phase II effort, the requirement is to prototype a real time (30 Hz) realistic simulation on a selected PC Based IG. In addition, with the wide variety of IG technology currently being utilized in Army simulation, the most important objective of the phase II effort is platform independence. Utilizing Dynamic Terrain (DT) Core, any IG should be able to implement dynamic terrain, with minimum changes required for integration.

Phase II efforts will integrate instantaneous tessellation with the soil dynamics subsystem. The soil dynamics module will be developed by the University of Iowa and integrated with the visual networking systems. The soil dynamics module requires gridded spatial elevation data in order to efficiently and accurately simulate terrain interaction. The soil dynamics module computes the deltas in elevation at each post location based on the vehicles current action (e.g. digging, sinking, slipping, etc.). The final data set is then supplied to the tessellation module to determine the best visual representation for the deformed terrain. The tessellation module then generates visual levels of detail for the newly deformed terrain and applies any texture modifications required to accurately represent the new terrain state. Dynamic texture methods will be implemented to achieve realism utilizing the textured polygon overlay method. By applying layers to an affected polygon, the appearance will change dynamically as deformation occurs. For example, as the blade of a plow cuts into a grassy area, not only would the earth be displaced (modifying the underlying geometry), but also the appearance of the deformed area would transition from grass to dirt to make the deformation more realistic to an observer. Levels of detail will be used to reduce the load on the graphics portion of the system. Physically, when any area is deformed, the highest level of detail will be modified. Visually, only those areas close to the eye point will be rendered using higher levels of detail. Areas further away from the eye point will use lower levels of detail to improve rendering performance. In order to maintain performance, the dynamic terrain software will need to manage database paging. Paging is a way of managing memory to maintain performance. Areas of memory that are not currently needed are paged out to the hard drive, thus freeing RAM to be used by other more critical processes. Conversion of the CCTT P3 STF terrain database to an OpenFlight format was originally planned, however due to schedule and budget constraints, a direct conversion of P3 from the Evans & Sutherland GDF format to the OpenFlight format will be implemented. The analysis regarding utilizing the SEDRIS STF format is still valid.

A dynamic terrain technology prototype showing the capabilities and improvements in phase II will be presented at the Interservice/Industry Training Systems and Education Conference (I/ITSEC) in Orlando, Florida from 27-30 Nov 00 in the STRICOM booth. Two exercises incorporating the above objectives will demonstrate successful implementation of the requirements. These exercises consist of a heavy and wheeled scenario generated by the Maneuver Support Battle Lab (MSBL), Ft Leonard Wood, MO. The exercises will show specific instances of dynamic terrain (such as a breach, footprints, explosions, buildup of soil on wheels/tracks, and effects of saturated soil on vehicles). The scenarios will be implemented using both manned simulators and ModSAF on a DIS network. As previously stated, the CCTT P3 (Ft Hood) database will be utilized as the terrain database. The architecture utilized for the exercises are outlined in figure 9, with the dynamic terrain implementation identified as Dynamic Terrain (DT) Core.

CONCLUSION

Currently, the synthetic environment lacks a real-time dynamic terrain capability. As the Army migrates to a medium force composition, dynamic terrain capability is instrumental to assist in training the combat support elements and the maneuver forces. With the advancing technologies of PC chipsets, a real-time implementation of dynamic terrain is now viable. With these advances, real-time, PC-based dynamic terrain interoperability is now possible in a distributed simulation environment. With a platform independent software solution, dynamic terrain can be implemented in the many simulations/simulators being utilized in the Army with minor changes to the software required for integration. As the synthetic environment becomes more robust and dynamic to meet the simulation needs, dynamic terrain is adding to that capability by adding an essential element to the maneuver force and the combat support elements.

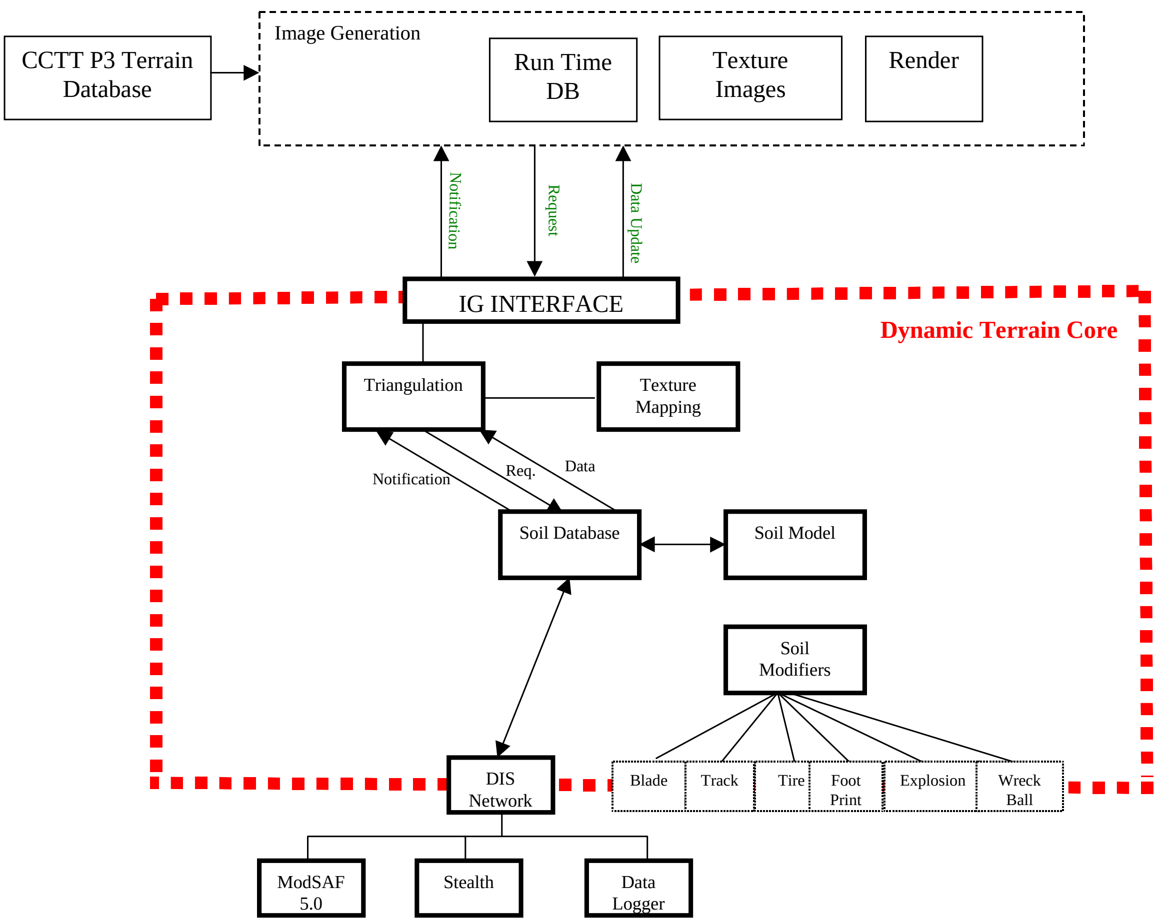

Figure 9

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Biographical Sketch**:**

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Synthetic Environments in Advanced Distributed Learning

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Abstract

This paper discusses the potential requirements to link modelling and simulation technology to the increasingly important training technology of Advanced Distributed Learning (ADL).

ADL is the fastest growing training technology for intra and internet based training applications and is currently being investigated by DERA for delivering an Army wide Unit Based Training (UBT) capability.

This UBT research programme has highlighted the necessary links and benefits that must be made by ADL to the Synthetic Environment (SE) domain. There are a number of emerging discussion papers defining the requirements for ADL in military training, including a NATO Simulation and Modelling Initiative. These papers all identify the need to draw from a wide range of modelling and simulation technologies.

An application on ADL, Unit Tactical trainer (UTT), has been identified that it will benefit by employing existing SE technologies. Such technologies include synthetic forces (e.g. MoDSAF). This paper identifies where we can benefit from the advances being made in SE's, allowing an increased utilisation of ADL.

Introduction

Synthetic Environments (SE's) can support all phase of the defence process (Figure 1) In a number of these areas the benefits of SE are already being realised. Notably, SE's are already providing a strong underpinning to procurement, via Synthetic Environment Based Acquisition (SEBA), Operational Analysis, and Training and Mission Rehearsal.

Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

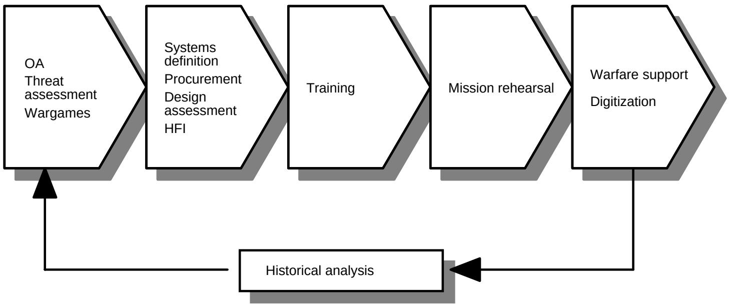

Figure 1: SE Application Areas in the Defence Process

There are a number of reasons why the SE approach is able to benefit the various stages of the defence process to such a large degree and they include:

- The reuse of models and data developed for an earlier stage in the process.
- Recording, controlling and manipulating data and modelling assumptions at the different stages.
- Varying model resolution, features and fidelity as the application dictates.
- Providing a controlled and highly visual modelling environments in which objective performance measurement can take place.
- Able to utilise models and data developed for different purposes in a common distributed research environment.
- The adoption of common software standards to maximise reuse and interaction.

Advanced Distance Learning (ADL)

Paralleling the growth in use and popularity of SE's has been the developments in ADL using both intra-nets and the inter-nets. Many training programmes that can be hosted over a/the web can draw on and link to SE component technologies. Computer Based Training (CBT) systems such as AS90 Training programme demonstrator designed for the Royal Artillery by Orchard Communications Design Group in 1998, draw extensively on SE models.

Figure 2: AS90 Trainer Demonstrator (courtesy Orchard Communications Design Group)

The vision for ADL is first to produce a resource for learning that can support local training needs (e.g. the military). Then, through the organisation of knowledge into reusable content, provide a system that through the web would be accessible to all for training and support activities. Ultimately it is hoped that a web based organisation of an encoded, sharable and reusable knowledge base can provide a personal support system for all human activities (Figure 3).

ADL phase	Information content	Access
Local intra and internets	Training programmes and operational support packages	Limited access, bespoke applications, military, industrial and academic organisations
World Wide Web (II)	Sharable organised knowledge structure to meet civil and military training needs	World wide access, limited content
Personal Assistant	All Human Knowledge	Real time wireless access, intelligently organisable, on demand

Figure 3: The ADL Vision

There are a number of initiatives underway to introduce a wide-ranging infrastructure to support ADL both at the service level, national level and internationally. It is likely that once the outcome of several policy initiatives (e.g. the Defence Training Review 2000) are considered, there will be a move to rationalise the delivery infrastructure across the services, and produce a tri-service infrastructure and training resource. Nationally there are a number of web-based infrastructures to deliver training to both industry and academia.

Internationally there are a number of panels (e.g. Technical Co-operation Panel Hum-2, NATO Modelling and Simulation, and NATO ADL Technical Team) that are seeking to ensure an adoption of common standards and international approach to the introduction and use of ADL. The USA initiative to provide a web based training resource that can leverage the civil community is based around the ADL Co Labs (DoD Strategic Plan for ADL,1999).

Unit Based Training (UBT)

One initiative at the service level by the British Army is a programme to develop an infrastructure for the delivery and management of Distance Learning. The Army infrastructure initiative is known as UBT. To support this, the MoD Applied Research Programme (ARP) 07 has constructed an Advanced Technical Demonstrator Programme (ATDP) in partnership with industry to validate and define the concept for the UBT infrastructure. The ARTD research programme is primarily designed to address three broad areas:

- Unit Training Management, which includes the management of security, shared data and training records, manpower and maintenance requirements, and cost effectiveness evaluation.
- UBT Technology and Demonstrator, which includes developing the ATDP hardware and infrastructure, developing international links, reviewing underpinning technologies and understanding the implications of programmes

that impact on UBT including Digitization of the Battlespace (Land) (DB(L)). Links to traditional SE's are also being addressed.

- ADL Training Requirements, Processes and Methods, which includes an analysis of the training capability gap UBT will address, and research to prove the training effectiveness of ADL. Research into training methodologies for ADL include reusable and sharable object models for ADL and guidelines for the selection, design, development and evaluation of authoring systems and courseware.

The ATDP will link a Royal Electrical and Mechanical Engineers (REME) package (technical training), a Combined Arms Training School (CATC) package (tactical training), and a Territorial Army (TA) package (unique training needs), to a DERA research hub with links to international sites including the US ADL Co-Lab (Figure 4).

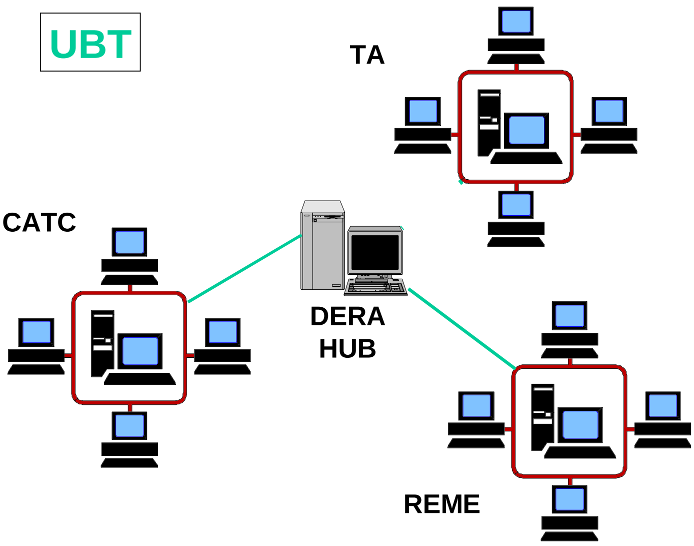

Figure 4: UBT ARTD Programme Concept

Applications on UBT

The UBT infrastructure is being designed to be able to deliver a wide range of training benefits and operational support packages for the British Army. In UBT, a broad concept of units is adopted including: Phase 1 initial recruit training through Phase 2 and 3 training at both the Army Training and Recruitment Agency (ATRA) and Arms Schools, to the unit level itself. It also includes training progression from individual through team and special to arm, to Collective Performance (CP) levels 1-3 within a combined arms environment. These training benefits and operational support packages include:

- The pre-collective skills (British Army CP levels 1-3) that underpin collective training.
- Individual and team component military skills.
- Skills underpinning the use of tools supporting the DB(L), such as GP3 (digitised operational command and control system) and QP24 (digitised logistics control), which in recent Army trials have been identified as being subject to acute skill fade.
- A wide range of military technical and educational courses, existing and new.

- Courses for career development, such as Vocational and Non-Vocational Qualifications (NVQ), etc.
- Training to meet the new demands for Operations Other Than War (OOTW) or Peace Support Operations (PSO).
- Provide a training audit trail.
- Provide unit level links to the US Unit Training programmes.
- Provide training in-theatre.
- Provide training on route to theatres (e.g. onboard ship).
- Provide training at home, for both NVQ and TA support.
- Provide asynchronous training, '**training anywhere any time'.**
- A host environment suitable for the proposed Unit Tactical Trainer (UTT) system.

Currently both a web-based and an intranet solution are being pursued. The web offers wide access but lowered security, though it is believed adequate for the levels of training anticipated. The intranet offers additional security, possible enhanced bandwidth (at a cost) but an associated low access. The feasibility of a combined system with firewalls between the Army WAN and the web has also been explored.

Unit Tactical Trainer (UTT)

The 1996 (UTT) Statement of User Requirements stated that, 'there is no effective training system that provides doctrine and tactical training for commanders within a unit. It is proposed that this capability gap should be addressed by a system known as UTT.' It is anticipated that by 2003/4 UTT will provide a Commercial Off The Shelf (COTS) training solution for tactical training through an LAN of PCs or as an application eventually hosted on the UBT infrastructure (Figure 5). UTT will provide all arms, collective, tactical training and skills maintenance at both the combat and combat support unit and sub-unit levels.

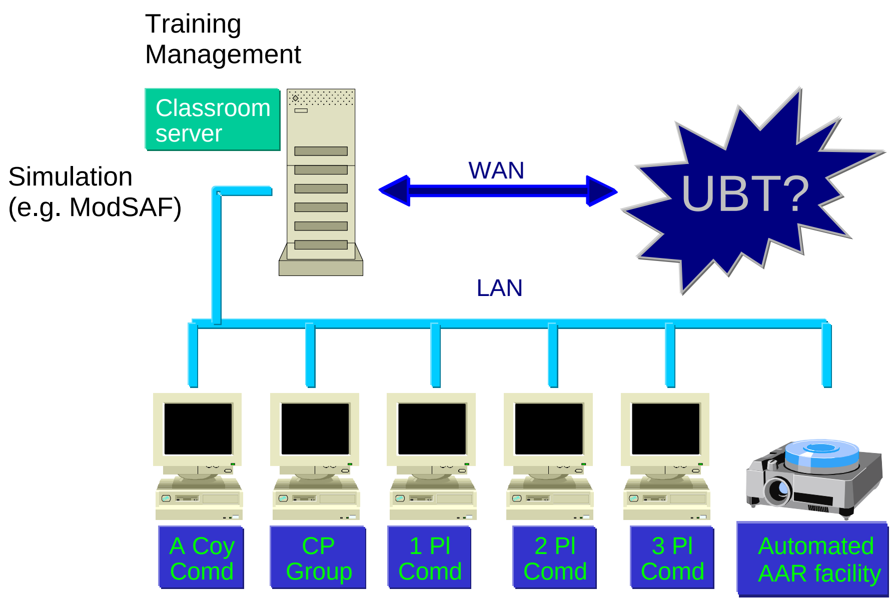

Figure 5: Unit Tactical Trainer Concept

The UTT concept test-bed has been developed utilising Modular Semi-Automated Forces (ModSAF) version 5.0 and the US Training Exercise Development System (TREDS) version 3.2 (Crissey, et al 1994). The concepts test-bed also highlighted the need to use objective training metrics and for them to be supported by an Army-wide training management system. Low trainer manning and the need for automated After Action Review (AAR) such as the Exercise Analysis for Collective Training (EXACT) system (Kelly, et al 1996) was also identified.

The emergence of training systems such as UTT, using SE components such as ModSAF, databases and exercise management systems, including AAR systems, which can be delivered over the web (e.g. internet compatible version of Janus - Brigade Combat Team) indicate the need for the SE community to be aware of web developments. These two scientific communities are now starting to come together and there needs and applications are beginning to overlap.

Common Standards

The standards that underpin the successful use of SE's, such as Distributed Interactive Simulation (DIS), High Level Architecture (HLA), ADL, Synthetic Environment Data Representation Interchange Specification (SEDRIS), etc., are matched in the web domain by emerging standards for packaging, referencing and retrieving objects.

The US DoD has established the ADL initiative to develop a strategy for using learning and information technologies to modernise military education and training. This initiative has defined high-level requirements for learning content such as reusability, accessibility, durability and interoperability. As a result of this, there has been an attempt made to specify a reference model that abstracts runtime constraints and defines a common interface and data scheme for reusable content - this is known as the Sharable Courseware Object Reference Model (SCORM). SCORM has now entered a test and evaluation phase, during which corrections, clarifications and improvements will be gathered. The eventual goal of SCORM is to allow individually tailored training to be delivered 'anytime, anywhere, to anyone that needs it.'

A reference model is needed to aid the successful implementation of the ADL initiative, which will require the issue of guidelines that are shared and observed by organisations that have a stake in the development and use of instructional technology materials. These guidelines may be of an international or national standard, agreed upon practices, recommendations, or de facto practices. If they are to be successfully articulated and implemented, they must be based on a common 'reference model.' Such a model will not actually replace the detailed models of instructional system design or practices that have been devised and adapted by specific organisations. Its purpose is to describe an approach to developing instructional material in sufficient detail to permit guidelines for the production of sharable courseware objects to be clearly articulated and implemented. There are three primary criteria for SCORM:

- Fully support articulation of guidelines that can be implemented for the production of sharable courseware objects.
- It must be adapted and used as much as possible by a wide variety of stakeholders.
- It must permit mapping of any stakeholders' specific model for instructional system design and development into itself.

It is estimated that investment costs could be reduced by 50-80% through the use of this model. These sharable courseware objects should be:

- Durable - does not require modification as versions of system software change.
- Interoperable - operates across a wide variety of hardware, operating systems and web browsers.
- Accessible - can be indexed and found as needed.
- Reusable - can be modified and used by many different development tools.

At its basic level, SCORM defines a web-based learning 'content model.' It can be seen as a set of interrelated specifications designed to meet the DoD's high level requirements for web-based learning content reusability, accessibility, durability and interoperability. In its current iteration, SCORM comprises three major elements:

- Course structure format - an Extensible Mark-up Language (XML) based representation of a course structure.
- Runtime environment - a definition that includes a specific launch protocol to initiate executable web-based content.
- Metadata (i.e. data about data) - a mapping and recommended usage of Institute of Electrical and Electronics Engineers (IEEE) LTSC Metadata elements (i.e. course, content and raw media Metadata).

Benefits of the Web for SE

Ensuring SE's are able to adopt these emerging standards will produce two major benefits. Firstly, that a part of the ADL community who that can utilise SE models and databases will be readily able to access them. Secondly, the web will provide an excellent data repository for the SE community. The benefits of a web-based database and model repository includes:

- Access to models for the SE community.
- An organising resource for SEBA.
- Reuse of SE models and data in ADL applications.
- Data organised for access, retrieval and use.
- Recording key facts (data sources, assumptions) origins of models, original purposes, updates and configuration control.

A number of initiatives as are under way to explore this option (e.g. Euclid 11:13).

Security

There are a number of barriers to the wide implementation of military models and data in and Internet environment. In particular, a number of practical issues do emerge in the consideration of security in utilising the web but many of these are cultural barriers and not technical. Barriers to the introduction of the Internet for SE and ADL applications can currently be seen to include:

- Identifying and challenging organisational 'Gate keepers.'
- Fears over job or role losses and threats to power (both expert and positional).

- Potentially unnecessary security requirements for selected Military data.
- Organisational culture (blame, secrecy and bureaucratic issues).
- Change overload in the training domain.
- Change to training support from learning.
- Hidden benefits in the 'status quo' systems.
- Problems of data ownership, authoring and data control.

Conclusions

This paper has briefly highlighted the need for the two communities of ADL and SE's to remain aware of the developments and trends in their respective domains and to be aware that their paths are due to cross. Early recognition of the emergence of new standards in the ADL community and their vision for the future will benefit the further expansion and wider adoption of SE's.

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The Use of Virtual Simulation for Dismounted Infantry Training

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Abstract:

This paper discusses the use of Virtual Simulation and Synthetic Environments (SEs) for the training of the dismounted infantry (DI) soldier. The paper covers the needs and issues for this training and gives a series of examples of active research applications including improvements in terrain fidelity.
The approaches for current Infantry training are outlined together with a broader review of other arms training. The development of virtual simulations/SEs as training media in all areas of military training is discussed. The limited examples of virtual simulation for DI is discussed, including the representation of DI in other simulations (eg the UK Combined Arms Tactical Trainer (CATT)).
Current thinking on the important characteristics for virtual simulation for DI training is outlined including the user interface, terrain, graphics, weapon simulation, networking, CGF and infrastructure. Within this the difficulties of providing adequate and useful infantry training simulations are highlighted.
Examples addressing the above are detailed. These include a desktop Infantry representation simulator for use in large scale networked simulations (eg CATT). Research directed at improving the terrain fidelity for infantry simulations is also be covered in detail.
Finally the strands for future work are outlined briefly including work on the required characteristics of Virtual Environments for effective training applications.

Introduction

This paper outlines the issues surrounding the use of virtual simulation for the training of dismounted infantrymen. A major research thrust has been underway at Cranfield University Royal Military College of Science to assess the potential requirements for training using virtual environments and to evaluate alternatives against some of these requirements. This paper discusses the issues, outlines some of the completed research and identifies the current and planned future activities.

The term virtual simulation is used to describe simulation with which a user interacts by using an interface that is intended to represent a soldier's equipment and portray the view and other features of the real world which he would encounter. Thus the user is immersed to some degree, in an environment which represents the real one. In comparison, live simulation is that where users are in a real environment using real equipment whose effects are simulated (an example here is a TESEX laser/MILES-based exercise). Constructive simulation is that where equipment is simulated and the system operators are simulated – human /user interaction may be an element but is limited to direction of units or broad control of tactics/movement and this does not involve using simulated controls representing the real systems.

Paper presented at the RTO NMSG Conference on "The Second NATO Modelling and Simulation Conference", held in Shrivenham, UK, 24-26 October 2000, and published in RTO MP-071.

Current Uses of Simulation for Army Training

Simulation of all types is in widespread use for army training worldwide and is increasing. Constructive and virtual simulations have advantages over other forms of training, for example they permit higher fidelity/realism than classroom training and are, of course, cheaper than field training.
Other benefits include

- reduced damage to the environment,
- ease of exercise design and construction,
- repeatability of conditions,
- analysis and after action review or replay and
- controllability of timing and flexibility.

This is especially true for simulations employed for commander training where the commander and his staff can be trained whilst his forces are represented within a simulation.

Examples of current or imminent virtual simulations include tank part- and full-task training simulators, the MILAN missile simulator, helicopter simulators and networks of virtual simulations in training systems such as Combined Arms Tactical Trainer (CATT) in the UK or the Close Combat Tactical Trainer (CCTT) in the US.
However the use of virtual simulation for infantry training is limited. The UK has the Small Arms Trainer (SAT) and the LAW simulator which train in the operation and limited use of these weapon systems. Both require a significant amount of specialist equipment and are limited to single or few participants.

In the US there have been more developments in the use of simulations of all varieties. There are similar weapons trainers to the UK and in addition considerable strides have been taken in evaluating simulation for other aspects. The Dismounted Warrior Network has been developed as a testbed applied to the 21st Century Land Warrior programme and for differing training options. In addition the US has deployed systems based on commercial games and is currently configuring Delta Force 2 for use as a small unit training tool.

One other aspect is worthy of note. As well as the use of simulation for training of infantrymen the representation of infantry in simulations aimed at training other arms has some deficiencies. There is a particular concern that systems such as CATT may not represent the infantry sufficiently realistically for the tank and AFV crews to develop adequate familiarization with tactics and procedures when engaging or operating with infantry.

Challenges for Infantry Simulation

The reasons for the slower adoption of simulation for infantry training in the UK and in the US are the difficulties associated with implementing appropriate systems.

These systems would vary according to the application but, for illustrative purposes, let us use a potential system where a soldier would don a Virtual Reality helmet of some sort and control a weapon. He would move through a simulated environment (displayed in his vision device) and detect and engage enemy forces who would also engage him. These enemy could be other VE equipment users acting against him or, alternatively, computer generated and controlled forces. He would also act with other members of his force, who would also be either other users of VE equipment networked with him or computer generated forces.

Some of the challenges in delivering this type of solution are as follows:

The User Interface

A tank interior can be mocked up and a crewman sees the outside world largely through sensors that can be readily simulated with computer displays, similarly helicopters etc. For a soldier the view needs to represent the real-world view from an individual in the outside world. Thus to be realistic a high fidelity 3d view surrounding the man needs to be generated and updated. This is potentially expensive and requires high fidelity databases, high fidelity displays, either a headset as described above or possibly projection systems surrounding the user. To drive this requires appropriately powerful processing systems. The infantryman's weapon ideally needs to be in his hands and needs to be operated in a realistic manner requiring tracking and other interfaces.

Cost

For a simulation system to be deployed in useful numbers for infantry training it must be sufficiently inexpensive. The UK will have a limited number of CATT facilities (2 initially) each capable of Battlegroup level training. A similarly small number of infantry training facilities might well be unusable given the number of infantry units and the wide training needs. For some intensive applications such a number of expensive highly capable systems might be appropriate. For other simpler training applications there would be the need for more accessible solutions. One method might be distributed systems, for example an expensive facility accessed remotely from other locations.

Need

Field training is still needed and always will be, particularly for infantry. Some training elements, even though amenable to using VE might not be required in anything other than as real field exercises because of the other elements that this brings.

Terrain Databases

One of the major problems of using virtual simulation for the training of dismounted infantry is the terrain database. These databases have been generated for other training purposes such as for vehicle simulators. This often means that the resolution of the terrain representation is relatively low. For an infantryman on the ground every bush, dip, valley, channel and mound is important, as they offer places of concealment.

Networking

The transmission of sufficient data defining his state, stance and activity in a understandable format usable by the other entities and components within a distributed simulation network provides a challenge. The support provided for articulation of limbs etc within the DIS protocol, for example, is very limited. This means that the portrayal of an infantryman simulator from other linked simulators would be unrealistic in appearance and actions.

CGF

One alternative for the soldier simulator system above is for all participants to be based on manned simulators. This clearly results in cost and effort implications each time an exercise is run. The better approach is to use computer generated enemy and also computer generated friendly forces if possible. The current state of the technology for providing either of these is limited. The simulations which provide infantry CGF lack adequate behaviours in many aspects and are frequently found to be unrealistic. To accurately represent infantry behaviour requires a substantive representation of infantry tactics and human behaviour.

Summary

Now it may be that these views are extreme. Research activity is geared to identifying the level of fidelity which might be required in these areas for differing applications, for example it may not be necessary for a full, high fidelity VR headset view for some applications, perhaps for a small unit leaders' procedural training simulation. It may be that a desktop interface is adequate and teaches enough of the principles without the need for greater immersion. As another example, it may be that simple CGF is adequate for small arms firing training. However for most applications all these points have some, albeit varying, validity.

Project Research Examples

RMCS have completed a number of research projects directed at these challenges.
These include

- an evaluation of the requirements to develop a basic networked Virtual Reality system for DI,
- the development of a demonstrator representing a DI within a networked VR system,
- the investigation and demonstration of a low cost interactive networked DI training system based on commercial products and
- the demonstration and trials of a desktop DI Trainer.

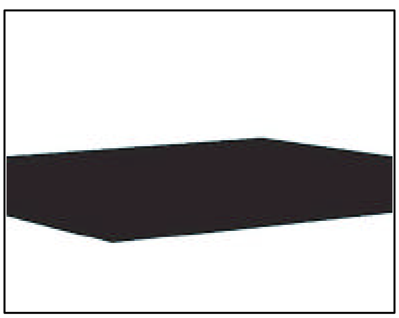
The following section of the paper outlines a selection of other activities which are either completed or ongoing.

High Detail Terrain Databases

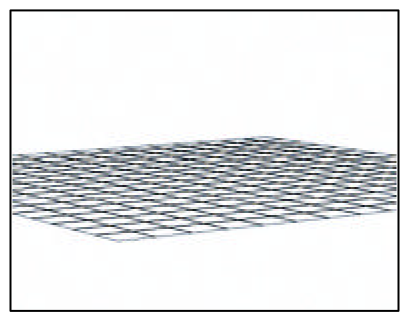
This activity investigated the feasibility of increasing terrain complexity by adding desirable and detailed features to an existing, sparsely cultured database.

Initial stages of this work were to make use of one of our original terrain databases. We wanted to be able to modify the terrain surface in some way, to add in the real terrain features of such importance to infantry, such as dips and mounds. The terrain databases available at RMCS are all polygon mesh based. Thus, to increase the terrain resolution, we need *increase* the polygon count for the mesh.

To illustrate the process, we can consider a single polygon within the surface mesh as shown in wire frame in Figure 1(a). The polygon represents an area of 128m x 128m which is typical of the polygon size in a representative terrain database representing Fort Hunter Liggett. The first stage of the process is to sub-divide the original polygon into a sub-mesh as shown in Figure 1(b). In the figure, the original polygon has been divided into 512 sub-polygons. To this new mesh, a noise filter can be applied, allowing the vertices of the mesh to be perturbed. The filter can be controlled in increase the amplitude and frequency of the perturbations. Figure 1(c) shows the result, with Figure 1(d) showing the solid filled image.



(a)



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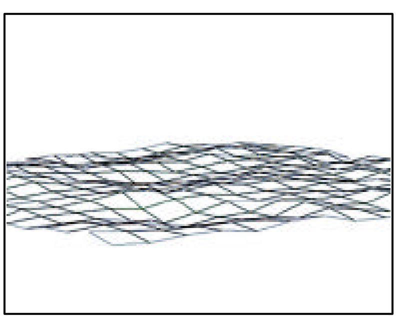

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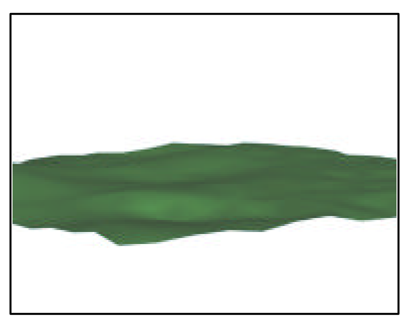

(d)

Figure 1: Addition of Terrain Complexity

Figure 2 shows the view of the new terrain surface from a viewpoint approximately 2m above the surface. It can be seen that the added terrain relief increases the feature richness of the surface adding in the required dips and mounds.

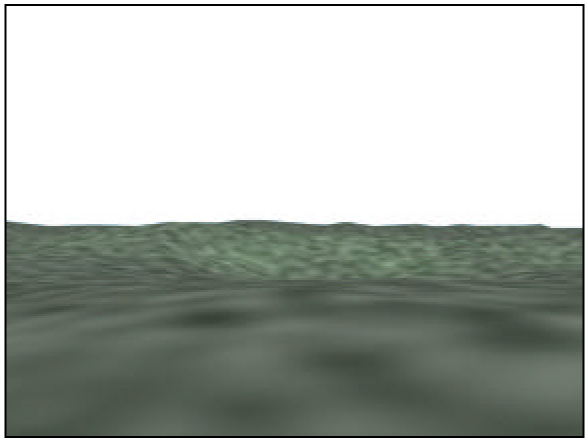

Figure 2: Final Result

Although, there is spare processing capability, if we were to apply the technique to every polygon in our terrain model, the system is likely to run at rate where it is difficult to interact with it. The current database contains approximately 80,000 triangles over a region of 30km x 10km, so this could increase by two orders of magnitude. However, for an individual infantryman, the terrain only in the immediate area need be at the higher level of detail. The aim is to implement a level of detail mechanism whereby as the infantryman moves over the terrain surface the terrain model is replaced with one of higher detail. However, since the switching between levels will occur at relatively short distances, the effect will be very noticeable. To overcome this, the technique of using a progressive mesh may be the solution. Here the detail in a model changes dynamically as the viewpoint moves.

One of the major problems in using this process is due to one of the classic inter-operability issues whereby the terrain model is not the same. This leads to unfair fight conditions, whereby one system believes he is hidden, but another clearly sees him. In addition, the technique does not add any terrain features such as roads, rivers, trees or buildings. In fact, if these objects already exist then the modification of the terrain surface will cause these objects to become miss-placed.

Flight Deck Officer

Currently the British Royal Navy Flight Deck Officers (FDO) are trained at RNAS Culdrose, Cornwall, England. Although their training is shore-based, they make extensive use of real simulation, learning to direct real helicopters onto a landing area. If, however, the weather conditions restrict aircraft flights or aircraft are unavailable, then the training makes use of a virtual simulator.

Research at the RMCS is looking into improving this virtual simulator. The current system requires the virtual helicopter to be flown by an individual, who is typically the class instructor. The pilot flies the helicopter, responding to the signals given by the trainee. The research at the college is looking into methods whereby, using suitable tracking devices, computer software interprets the arm movements of the trainee and the corresponding signal determined. This is then fed into the dynamics model of the helicopter, thus alleviating the instructor from needing to actual fly the craft. Such a system would allow for more than one trainee to be trained at a time and would allow all of the benefits of computer-based training to be applied. Figure 3 shows a still-image from the research system.

Figure 3: Flight Deck Officer Virtual Environment

It is hoped that this work will be applicable to the training of dismounted infantry, in that the same techniques developed for the identification of the arm signals of the FDO could be used for those of an infantry commander.

CATT Infantry

This project completed by Maj. Hutchinson was designed to develop better representation of dismounted infantry not for infantry training per se but rather to improve the representation within simulation systems such as CATT. The project constructed a new plug-in dynamics model for the CrewStation2000 vehicle simulator. Figure 4 shows the crewstation in operation.

Figure 4: CrewStation in Operation

The dynamics model simulates an individual infantryman, giving the ability of the user to move over the terrain surface, change his stance and to aim and fire a weapon as shown in Figure 5.

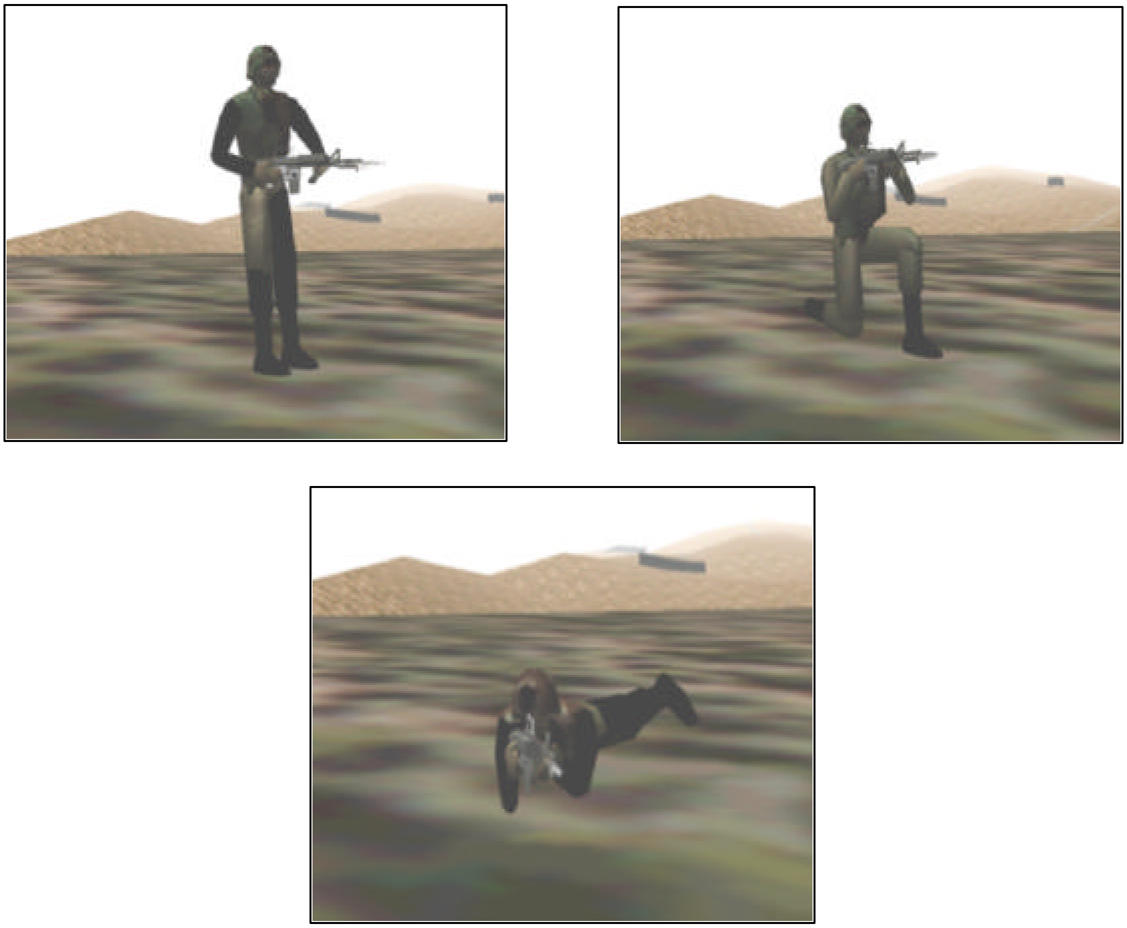

Figure 5: Dismounted Infantryman

Figure 6 shows the view as seen through the gun sight when the operator is aiming his weapon.

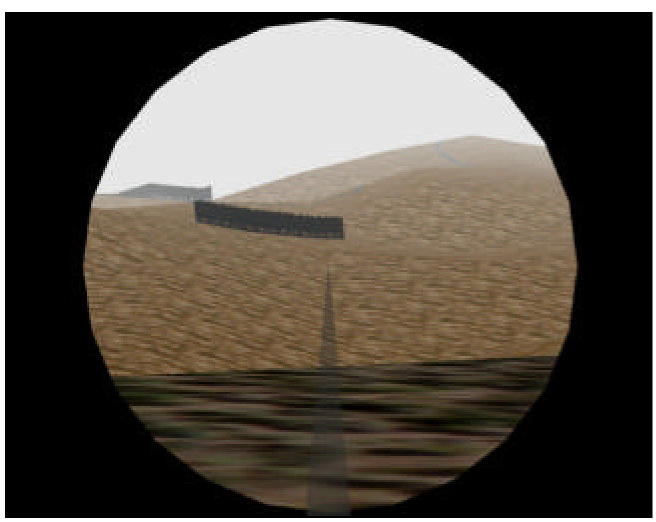

Figure 6: Dismounted Infantryman Gun Sight

This project overcame significant technical challenges and has provided a working and more representative DI simulator which is used at RMCS for participation within distributed simulations. The simulator still requires one human operator to control one DI. However, the project also laid the foundations for further work to develop a system which would allow a single controller to operate and command several dismounted infantrymen as a way of improving DI representation within distributed simulations in a more efficient manner.

Future Plans

Cranfield University at RMCS are continuing the research thrust in several concurrent strands.
Two initiatives have been commenced in late summer, the first to examine distance estimation in VEs in comparison to the real world and the other into the feasibility and adequacy of transfer of navigation skills developed through training in VE.

The plan for other research is as follows. To review infantry training including the exercise structure, the ordering of training and the details of the skills required to be developed with each training element and to cross compare these against the capabilities for VE to train in these types of tasks.
From these activities a shortlist of those infantry tasks that appear most amenable to some sort of VE will be identified. These will then be further filtered by evaluating whether there would be benefit (especially in cost and safety aspects) from being performed with a VE.

This process will act as the direction for further research and is intended to formulate several other research activities to build prototype VE systems and conduct trials with these in varying configurations to ascertain whether they will support the training, whether the skills learned in VE transfers to the real world.

Conclusions

There are significant challenges in applying simulation to the training of dismounted infantry. Much research is required to improve the capability of technology to meet these challenges and to better understand the appropriate form and characteristics of the types of systems which might fulfil the training requirements in the most effective and cost efficient way.
Cranfield University has completed a number of research activities directed at this area and is actively continuing this work.

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Aircrew Mission Training Via Distributed Simulation – A NATO Study

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1 Background

This paper is about the future potential in NATO of Aircrew Mission Training via Distributed Simulation, or MTDS. A Military Applications Study (known as SAS-013) on MTDS has just concluded, having been sponsored by the NATO Research & Technology Organisation (RTO)[1], through its Studies, Analysis and Simulation (SAS) Panel. The study report will be published shortly. The task of the study was

> "To assess the potential of advanced distributed simulation to complement live flying training in order to enhance NATO capability to conduct combined air operations."

This could be re-phrased as "How can NATO apply recent improvements in distributed simulation technology to enhance current and future NATO training for air operations?" Note that, according to NATO definitions (source: NATO AAP-6), *Combined Operations* are defined as operations between two or more forces or agencies of two or more allies. *Joint* is defined as activities, operations, organisations, etc., in which elements of more than one service of the same nation participate.

This paper will discuss some of the results of the SAS-013 study and will describe plans for further work.

The SAS-013 study has been conducted by a multi-national Study Team, led by the UK, consisting of serving Air Force personnel and national experts in simulation technology and aircrew training from Belgium, France, Germany, Italy, The Netherlands, Turkey, UK, and the USA. Team members also included representatives from the aircraft and the simulation industries.

2 What is distributed simulation?

Distributed simulation can mean many things to many people. In the present context, advanced distributed simulation is about enabling a collection of compatible advanced flight simulators to be linked together via modern networking technology in order to create a shared virtual "battlespace" in which all components can participate to conduct operational training and mission rehearsal tasks. In the context of the NATO study, this concept has been given the label "MTDS" - Mission Training via Distributed Simulation - in order to distinguish it from various national initiatives, such as the US DMT (Distributed Mission Training) programme.

This paper represents the views of the author and should not be taken to represent MOD or RAF policy

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Figure 1 illustrates the concept, in which examples of flight simulators from several nations are linked together in a common simulated battlespace, which can also include command and control elements such as AWACS. In the illustration, a Tactical Control Centre[1] is also shown from which a training exercise is controlled and managed.

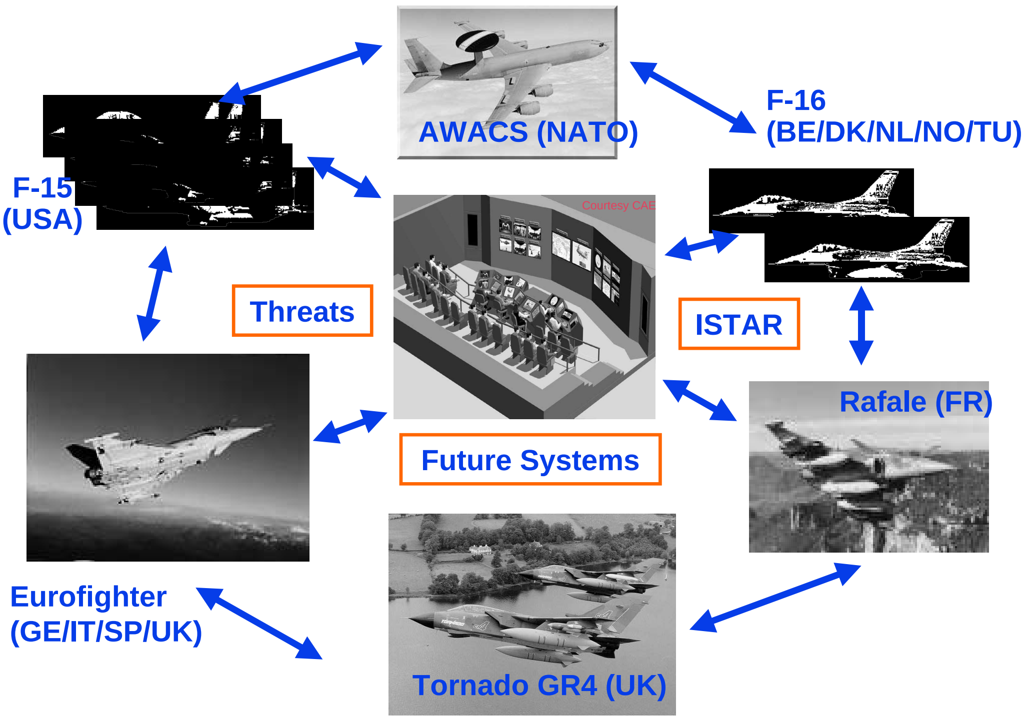

Figure 1 Vision of distributed mission training

3 Statement of the Problem

There is growing interest in NATO in the potential use of advanced distributed simulation for team and collective mission training for military aircrew. Live flying training is becoming increasingly limited due to a combination of factors, including lack of airspace availability, environmental and security constraints, concern about consumption of aircraft flying hours and airframe life, the cost of major exercises and limited opportunities to practise co-ordination of critical multi-national NATO air missions in a representative operational environment, complete with threats. Peace-time constraints typically preclude full operational use of Electronic Warfare (EW) systems, defensive aids such as chaff and flares and firing of live weapons. Data links are also extending the "tactical reach" of an air package. Thus, training methods have to adapt.

Combined forces from a number of member nations typically conduct NATO military operations. The collective nature of these operations means that members of the

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1 Illustration of UK Medium Support Helicopter Aircrew Training Facility courtesy of CAE Electronics Ltd.

NATO air forces must be prepared to operate as members of multi-national teams. This requires they understand collective doctrine, tactics, planning, and C3I. For example, in order to prepare and execute successfully a collective strike mission, mission commanders and flight leaders must know the capabilities of the various weapon systems from each nation. In addition, they must understand how to integrate these weapon systems in such a way as to maximise the overall capability of the resulting strike package and they must monitor and control the overall execution of the mission. Preparation for such operations includes training at the individual level, extensive team and inter-team training at the national level, and recurring training in combined air exercises involving a number of nations.

NATO air forces need a virtual environment in which to acquire and sustain the skills needed to perform successfully as part of a multi-national combined air force. This virtual environment needs to be inexpensive enough to be used frequently, be readily available at home station or some other appropriate location, and be secure enough to be used without revealing operational details and tactics to unauthorised personnel.

4 NATO Air Training Practices Today

NATO Air Doctrine is evolving towards more Composite Air Operations (COMAO)[1], with multiple nations contributing a variety of different assets. In a typical COMAO, 20 to 40 aircraft fly in a package, often referred to as a “Gorilla”. The composition of any package is based on the specific aim of the mission. Such a package is shown in Figure 2, where the various roles such as Sweep or Escort might be fulfilled by different nations. Vital support functions - AWACS, AAR and EW - are also shown.

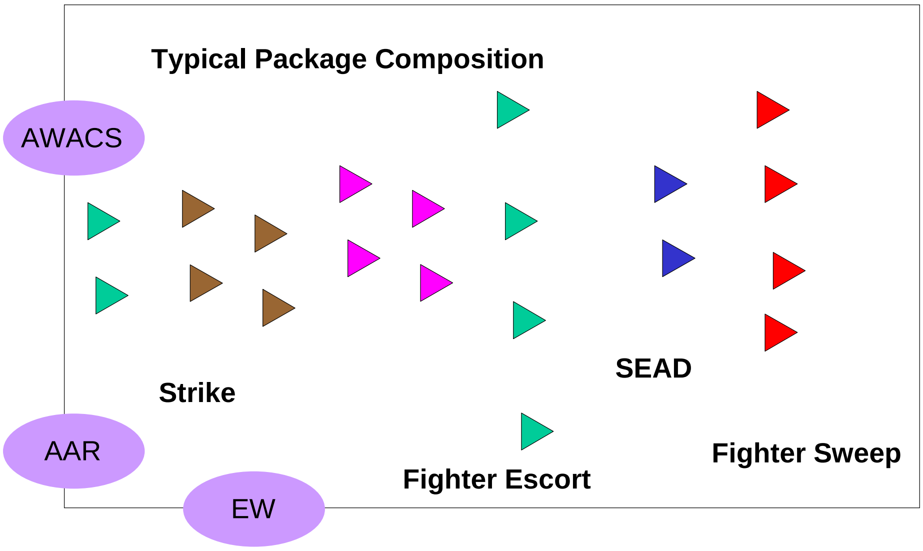

Figure 2 Example Multi-National Package in a COMAO Mission

1 Composite Air Operations (COMAO) are defined as packages of aircraft comprising attack aircraft, supported by AD and SEAD assets, under the command of an overall mission commander. Co-ordination of COMAO packages with AAR, AWACS and EW aircraft is the responsibility of the CAOC.

Opportunities to prepare for COMAO-style operations are limited. NATO has established the “Tactical Leadership Programme”, better known as the TLP, with a base in Belgium. The aim of this programme is to foster tactical leadership in large packages. During flying courses, experienced aircrews (2-ship or 4-ship leaders) learn to plan and to execute complex missions as leaders of a 30-aircraft package, typically including air-to-air, air-to-ground, reconnaissance, SEAD, EW, AAR and AWACS assets. Usually, these exercises take place partially in uncontrolled airspace. TLP is widely acknowledged as providing some most valuable opportunities for NATO collective air tactical training. NATO air training practices today also include the annual “NATO Air Meet” (NAM) exercise, where participating nations may send 4 or 8 of their best aircrews to fly COMAO and to discuss tactics with the other NATO aircrews. Major national exercises, such as the US “Red Flag” series, also provide valuable training opportunities.

5 Training needs

As part of the SAS-013 study, a typical scenario and mission, or “reference mission”, have been defined and then analysed to identify the skills and competencies required by the aircrews involved, and hence the training requirements. The reference mission is embedded in the scenario and together they have also served to define the key elements of a distributed training environment to meet the mission training requirement.

It was assumed in the SAS-013 study that aircrew members participating in mission training for combined air operations possess the basic individual and team skills needed to be categorised as “combat ready”.

For such aircrew to be effective as members of a multi-national force, they must train to operate as part of a collective involving two or more teams from two or more countries. In order to meet this training requirement, aircrew must master the skills necessary to employ their individual weapons systems effectively in accordance with national and NATO standards. In addition, they must also master a number of team skills involving communication, co-ordination, planning, decision making, and situation assessment that will be exercised in a complex multinational operational environment.

An exercise based on MTDS offers the opportunity for national and multi-national training of aircrew to:

- Refine individual and collective skills in complex, interactive, and uncertain mission environments that are difficult or impossible to duplicate in peace-time training;
- Develop the flight lead and mission commander skills that are necessary to successfully plan, execute, and assess combined air operations.

Advanced distributed simulations provide an effective means to train reasoning skills, meta-cognitive skills, risk-assessment skills, and communication skills without the overhead and complexities of real-world training. In addition, simulations can be controlled and repeated to ensure that aircrews receive the structured experiences needed to develop specific skills. Scenario events can be carefully crafted to provide specific stimulus-response opportunities that are tied to the training objectives. This means that opportunities to develop or exercise specific skills are directly tied to scenario events so that mastery can be assessed. This linking of training objectives and scenario events helps to ensure that valuable training time is focused on essential skills.

6 The state of the art in distributed simulation technology

The study has reviewed the state-of-the-art in advanced distributed simulation and future trends. It has done this in two ways, by looking at the technology itself and also by documenting national initiatives and experience relevant to Mission Training via Distributed Simulation.

Simulation technology has advanced substantially in the past 5 years, especially in visual display quality, representation of the operational environment, and computer generated forces. A modern advanced simulator can provide a virtual battlespace with any real-world geography and including photo-realistic imagery, provided the data and imagery are made available. It is possible to create a realistic threat environment, where threats fire back. Costs have also fallen, so that multi-ship configurations for collective training and COMAO are becoming affordable. While further improvements are still needed distributed simulation systems can be put together and are usable today.

As part of its work, the study has identified national initiatives in distributed simulation. A variety of demonstrations and experiments have been conducted, including

- Multi-Distributed Training Testbed, MDT2 (US) 1996 (Taylor, 1996)
- TRACE - Transatlantic Research in Air Combat Engagement (US/GE)
- EUCLID RTP 11.3 demonstration of a Complex Air Warfare Training System, 1997, (GE, NL, TU, UK)
- Joint Project Optic Windmill (NL)
- STOW97 (US/UK) Nov 1997 (Budge, 1998 and Hobden, 1998)
- Air Defence Synthetic Environment (UK) Feb 1998 (Gale and Pugh, 1998)
- Roadrunner 98 (US) Nov 1998
- Trial Ebb & Flow (UK) Feb 2000 (McIntyre et al, 2000)
- ULT-JOIND (Unit Level Trainer - Joint Operations Integrated Network Demonstrator), (NL) 2000

Experience gained through these initiatives (eg Gentner, 1999; George, 1999) at such research facilities as the US Air Force Research Laboratory, at the Defence Evaluation and Research Agency in the UK and at the TNO in the Netherlands show that there is hard evidence of the feasibility and utility of distributed simulation. It is not just a dream. There is still a lot to do, however, to make such activities usable on a regular basis.

Procurements of a new generation of advanced aircrew training systems, with the potential to be part of a distributed simulation mission training exercise, are also in progress in many nations. These include

- In the USA, the USAF Distributed Mission Training (DMT) Programme for Air Combat Command, with F-15C 4-ship simulators installed at Eglin and

Langley AFBs in 1999, the first step in achieving a vision of a "Joint Synthetic Battlespace" by 2010.

- In the UK, a new generation of fast jet mission simulators for the Tornado GR4 (RAF), and Eurofighter (RAF) and, for the helicopter force, the WAH64 Apache Longbow (Army) mission simulators and the Medium Support Helicopter (RAF) simulators. All of these training systems have the potential to be linked to a wide area network.
- In Canada, plans for the CF-18 Advanced Distributed Combat Training System, part of an Advanced Distributed Mission Simulation concept.
- In France, the Combat Training Centre (CTC) at Mont de Marsan.
- Germany, Italy, Spain also have plans for Eurofighter simulators.
- Netherlands (with Norway and Denmark), F-16 MLU Unit Level Training Devices.

Simulators for MTDS have to meet certain requirements. Not only must they be network-capable, employing standard message protocols such as DIS or HLA, they also need to ensure common representation of the operational environment (geophysical, weather and tactical) and interoperability in terms of compatible system models and behaviours. Some guidance is given in the study report.

7 Technical and training challenges

Many technical and training challenges have to be met in order to establish MTDS as an effective method for advanced aircrew mission training. These include

- Infrastructure - suitable networks to be available
- Common data - shared : environment, threats etc
- Data Security - policy and technical

Simulation technology is steadily becoming increasingly capable, but there are still critical technology areas, including:

- Improved visual systems, especially display technology
- Better representation of the operational environment (day, night, all weather) and methods to exchange common databases
- More realistic behaviours in Computer Generated Forces
- Compatibility and Interoperability - much more than just networking – issues include correlation between visual/sensor databases and interactions between entities
- Standards e.g. in networking and in database interchange
- Creation and management of an affordable and usable network infrastructure
- Methods and tools to support the whole Exercise Management life cycle
- Multi Level Security

8 Principal findings

The study has found that

- Mission Training via Distributed Simulation (MTDS) offers promise of substantially enhancing NATO's operational effectiveness in COMAOs and other air operations, and is viable now.
- It is increasingly recognised that, in isolation, live flying training cannot prepare NATO aircrew for future composite air operations (COMAO) – there is a "training gap".

- Mission Training via Distributed Simulation (MTDS) can begin to fill the “training gap”, by overcoming some of the limiting factors in live flying training, particularly
  - representation of the operational environment
  - complex ROEs, C3I and restrictions on full use of EW, defensive aids and weapons
  - cost of flying training (Exercises, attrition, aircraft life)
  - availability of aircrew, airframes and airspace, including ranges
  - safety, environmental and security concerns

The study also notes that MTDS and live flying are complementary, and that MTDS would offer opportunities to extend the scope of training to include the chain of command.

MTDS has potential to

- Provide multi-national training opportunities in large force employment
- Include high-value assets (AWACS) in simulation
- Practise co-ordination, procedures, tactics
- Explore “what if’s” - more effective operations
- More focused use of flying training time
- Involve wider air operations community - CAOC, Intel
- Mission rehearsal

MTDS can also provide the means to assess future systems and concepts, to develop and try out doctrine and tactics, to assess proposed force capabilities prior to participation in operations, and to support simulation based acquisition. Indeed, nations willing to participate in NATO air operations could well be expected to join an MTDS exercise first.

9 How should NATO proceed?

The study recommends that

- NATO should recognise that mission training via distributed simulation has great potential to complement live flying training in order to enhance NATO capability to conduct combined air operations.
- NATO should declare its intent to exploit modern distributed simulation to improve its capability in air operations.
- NATO and the Nations should pursue the exploitation of Mission Training via Distributed Simulation.

It will, however, take some years to establish MTDS in NATO. Both national and NATO initiatives are required. For example, nations need to acquire suitable national simulation assets (the study report offers guidance on the required technical capability). The first relevant national systems (e.g. in the US DMT program) were delivered in 1999 and are evolving in other nations. There is also a need for research and demonstrations, both nationally and in NATO.

Among the recommendations of the SAS-013 study are some proposals for further work. These include the formation of a Concept Development and Demonstration Task Group (SAS-034). While the study has said the concept of MTDS “is a good idea”, it has conducted no actual trials or exercises. Some real experience is now needed before NATO can bring MTDS into regular use. Thus, the aim of the SAS-034 task group is to spread awareness of MTDS throughout the NATO military community and the nations, and to conduct a preliminary multi-national demonstration of the potential in NATO of aircrew mission training through distributed simulation. This will be undertaken in collaboration with the MSG-001 task group of the NATO Modelling & Simulation Group.

The SAS-034 Task Group, which will begin work in Spring 2001 and last for 3 years, is currently being formed, and its Terms of Reference and programme of work are being defined. The Task Group team currently includes participation from Canada, France, Germany, Italy, The Netherlands, UK, and the USA. Further participation from the operational community in nations and in NATO is being sought, as well as from other panels of the RTO.

It is also planned to hold a NATO Symposium in 2001 on the theme “Mission Training via Distributed Simulation in NATO - Achieving and maintaining cost-effective readiness in the 21st Century”.

10 Concluding remarks

Preparation for effective conduct of air operations in NATO and exploitation of smart weapons will be founded in future on mission training via distributed simulation.

Some follow-on initiatives are now required, and are being planned, to develop the concept and to enable distributed simulation to be used as an effective training method in the NATO air community. These activities include a need for experiments and exercises

- to learn more about how to achieve real training value from MTDS in collective air operations
- to acquire further experience in applying the technology

Nations are already starting down the road towards acquiring simulation assets that will be the building blocks in NATO MTDS.

Now is the time to take action on technical requirements and standards to avoid future interoperability problems – we do not need to wait until all problems are solved. Co-ordinated research is required in nations, particularly in the areas of collective training for air operations, distributed simulation technology and interoperability.

An evolutionary programme needs to start now to deliver NATO MTDS capability via Concept Demonstration, followed by an implementation plan leading ultimately to full exploitation.

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Glossary of abbreviations

AAR	Air-Air Refuelling
ADSE	Air Defence Synthetic Environment
AFB	Air Force Base
AWACS	Airborne Warning and Control System
CAOC	Combined Air Operations Centre
COMAO	Composite Air Operations
CTC	Combat Training Centre
DIS	Distributed Interactive Simulation
DMT	Distributed Mission Training
EUCLID	European Co-operation for the Long Term in Defence
EW	Electronic Warfare
HLA	High Level Architecture
MLU	Mid-Life Update
MTDS	Mission Training via Distributed Simulation
NAM	NATO Air Meet
NATO	North Atlantic Treaty Organisation
NMSG	NATO Modelling and Simulation Group
ROE	Rules of Engagement
RTO	Research & Technology Organisation
RTP	Research and Technology Project
SAS	Studies, Analysis and Simulation (Panel)
SEAD	Suppression of Enemy Air Defence
STOW	Synthetic Theater of War
TLP	Tactical Leadership Programme
TNO	Applied Research Laboratory, the Netherlands
ULT-JOIND	Unit Level Trainer - Joint Operations Integrated Network Demonstrator

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Computer Generated Forces Based on Tactical Application of Principles of Combat Survivability

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Abstract

Computer generated forces (CGF) technology has succeeded over the past decade due in large part to the collaborative efforts of computer scientists and of military experts. This collaboration was largely driven by various programming, networking and other computing demands that, in turn, were owned by and thus articulated by software managers. Consequently, military expertise was applied principally in response to software programming requirements. That is, software development - understandably - led CGF development. At the conclusion of the ten-year period since a heralded DARPA-U.S. Army demonstration of large quantities of CGF networked over a wide area network, it is arguable that CGF technology has stabilized, technically and culturally. We propose that such stability supports the beginning of a shift in which military science, as opposed to computer science, drives subsequent evolution of CGF. This shift is necessary because, whilst CGF have certainly been shown to be useful over this period, it is arguable that current CGF implementations do not support the manoeuvrist doctrine that NATO armies espouse. We believe that this shift in CGF "ownership" may lead to significant increases in the value of CGF technology in line with the requirements of the user community. Pursuant, we contend that the technical domain known widely as combat survivability analysis offers a potentially useful context for research. Ball's (1985) classic articulation of survivability analysis outlines six combat dimensions that suffice to define the combat relationships between and among any or all platforms and/or relevant battlefield organizations. The dimensions are evaluated from the perspective of each entity by estimating the probabilities of a threat existing, being detected, identified and tracked by it, it successfully aiming, firing and detonating some munition and, finally, the probability of destruction by that munition. The calculation of these probabilities allows an entity to estimate a probability of survival for any set of circumstances in which it finds itself. We argue, that an awareness of this threat, when compared to an individually generated aversion to risk, will allow the entity to drive its behaviour in a way that is more in line with the way that real people operate and the way that we would wish a manoeuvrist entity to behave. We outline this approach, together with a program of research that we hope to undertake to validate our ideas.

INTRODUCTION

Recent years have seen enormous changes in the defence and security environment. Increasingly it is impossible to define defence requirements in terms of threat, and many armies are moving towards a capability-based stance. The lack of an obvious threat also means that defence budgets are reduced and that defence planners are constantly looking for ways to make less money go further. Environmental pressures mean that training areas are at a premium, and it is increasingly difficult to conduct large-scale manoeuvre exercises. Weapons systems are becoming ever more technical and costly. It can be seen that these constraints demand new methods for force and system development and training. Modelling and simulation is hence playing an increasingly prominent part in the development of combat forces and has been found to offer cost-effective applications in the training, testing and assessment of military forces and equipments. It is in this context that the modelling of human behaviour in combat has become increasingly important in defence modelling and simulation.

Aim

Our aim in this paper is twofold: Firstly, to outline some of the key deficiencies with the representation of human behaviour in current computer generated forces (CGF) implementations in the context of user requirements; and secondly to outline our plans for research into a method which may improve this representation for training purposes.

Organisation of the Paper

In essence the paper gives the motivation for and an outline of planned research into improving human behaviour representation (HBR) that will be undertaken at RMCS and IST over the next year. We will start by

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reminding ourselves of the requirements of the user community. NATO armies now espouse a manoeuvrist approach to the conduct of operations, and we will briefly outline this philosophy. We will then consider the main current implementations of CGF and identify weaknesses with them in the light of these requirements. Following a brief description of ModSAF, including the mechanism for the generation of behaviours, we will introduce the concepts of Combat Survivability Analysis[1]. We will use these concepts to suggest a mechanism whereby CGF entities within a simulation can reach a perception of the threat that they face - in a way that real combatants might – and take action depending on each individual entity's aversion to risk. We suggest that this addition will introduce an unpredictability in entity behaviour which is not currently present and is representative of real combatants rather than being purely random. Further, we contend that this unpredictability will allow the generation of more realistic-behaving entities for use in training simulations.

MANOEUVRE WARFARE

War is a human activity. The human element is central to the causes of war, its conduct and its resolution. Napoleon Bonaparte[2] famously stated that "*in war, the moral is to the physical as three is to one*". To develop Napoleon's comment further, any discussion of combat that considers only physical factors, neglecting the human ones, is, at best, a 25% solution.

Current British military doctrine[3] emphasises the central role of Manoeuvre Warfare Theory on the conduct of operations. This doctrine envisages a successful battle or war being fought through the prosecution of a judicious combination of attrition and manoeuvre. In this sense attrition means the destruction of men, forces and materiel and manoeuvre means movement and action aimed at denying the enemy freedom of action and rendering any action he does take irrelevant. Utilised on its own, either approach is flawed. In particular, attrition on its own is unlikely to be successful unless the General that seeks to attrite has a great advantage in combat power. Even this is far from a guarantee of success. Research suggests that numerical advantage is amongst the worst predictor of combat outcomes[4].

Manoeuvre warfare seeks to create the psychological conditions for defeat in the mind of the enemy. As such it thrives on fear and uncertainty in battle. Attrition will play a part in this process, but, as Clausewitz said, "*military activity is never directed against material force alone: it is always aimed simultaneously at the moral forces which give it life, and the two cannot be separated*[5]" As Grossman has stated, "*the essence of manoeuvre warfare (is) that you defeat the enemy's will to fight rather than his ability to fight*[6]. The German "blitzkrieg", which proved so successful in the early years of the Second World War, furnishes an example of the relationship between attrition and manoeuvre. The distinguishing feature of the blitzkrieg offensive was the avoidance of battle[7] through the utilisation of suppression. This tactic rendered the defenders actions irrelevant and ensured that they were constantly reacting to changing circumstances. The blitzkrieg thus drove events, leading to the rapid collapse of the defender's will to continue. As Hughes has said "*no attrition model can explain the blitzkrieg phenomenon, which was achieved by an intensive, local suppression of the defender's ability to resist*[8].

It can thus be seen how manoeuvre warfare seeks to attain victory through the mind of the enemy, rooting out his critical vulnerabilities and exploiting them. This is the context in which trainers wish to train and analysts wish to conduct their analysis. The implicit thesis of this paper is that the current generation of modelling and simulation tools do not sufficiently support this process. We would concur with Pew and Mavor, who state that, at present, it appears that "*users of military simulations do not consider the current generation of HBRs to be reflective of the scope or realism required for the range of applications of interest to the military*".[9]

PROBLEMS WITH CURRENT CGF IMPLEMENTATIONS

What CGF are and why current implementations are not good enough

CGF are "computer representations of vehicles and humans for use in simulations"[10]. They represent a simple and cost-effective way of populating a synthetic

[1] Ball, "The Fundamentals of Aircraft Combat Survivability and Design".

[2] In a letter to his brother, then Governor of Spain, 27 August 1808. Quoted in Tsouras, "Warriors Words".

[3] Directorate General of Development and Doctrine, "ADP Operations".

[4] Hughes, "Two Effects of Firepower", quoting research conducted by Robert Helmbold.

[5] Clausewitz, "On War", 157.

[6] Grossman, "Defeating the Enemy's Will", 142.

[7] Simpkin, "Race to the Swift", 34.

[8] Hughes, "Two Effects of Firepower".

[9] Pew, "Modeling Human and Organisational Behavior", 19.

[10] Pew, "Modeling Human and Organisational Behavior", 38.

environment[11] (SE) with entities. CGF entities may be used to provide an enemy force or flanking or supporting friendly forces. A single operator can control many computer-generated entities, reducing the manpower bill for the conduct of simulations. Thus a typical SE will consist of entities controlled by humans (manned simulators) working alongside or against entities generated by computer. Together, these entities will occupy a common synthetic world, allowing interaction between them.

An ideal CGF can be seen as being the integration of physical models (weapon systems, sensor suites, etc.) with controlling behavioural aspects (command, control, communication, situational awareness and the other less tangible human factors such as physical degradation, fear, leadership and morale, to name but a few). The physical models represent the state and activity of the military hardware within the simulation. Models such as this have been the subject of much work in the past, and it appears to be fair to say that they are reasonably well understood[12]. The controlling behavioural aspects of the simulation determine how the entity behaves in a given set of circumstances. The aspiration, at least, is that human-controlled entities within the simulation cannot distinguish computer-generated entities from other human-controlled entities. Unfortunately, general consensus would appear to be that we are still some way off achieving this level of credibility. Pew and Mavor, writing in the most recent and definitive source on HBR for combat models and simulations, state that "*it is fair to say that, in terms of models in active use, the introduction of human behavior into military simulations is in its infancy. However, because of the wide range of potential uses of these kinds of models, it is badly needed to create more realistic and useful evaluations*"[13]. Further, it would appear that such models do not have the confidence of the user community. In a book likely to be on the reading list for a student at Staff College in the UK or the USA, Robert Leonhard, a serving US Army officer, states that "*the main problem with computer modelling is that it is incapable of simulating the true essence of war. Computers are perfect for investigating ballistic equations, the durability of armor, and the lethality and radius of munitions. But the state of computer simulation in the US Army does not allow for proper evaluation of fear, morale, indecision, deception and exhaustion, although history teaches us that these factors and other intangibles are the crucial determinants of a conflict. In short, computer-generated armies lack critical vulnerabilities*"[14]. Whilst the state of HBR was of a significantly lesser standard when this work was written than it is now, the authors would contend that the thrust of Leonhard's point is still very much true - that current implementations of CGF generally fail to meet the user requirement. CGF thus need to be improved in line with user requirements if they are to continue to be considered useful

CGF users and their requirements

Simulations and synthetic environments are used across the defence spectrum. Pew and Mavor identify three primary classes of simulation user; those that use simulations to train individuals or teams; those that use them to conduct analyses designed to inform development of doctrine and systems or support procurement decisions or contingency plans; and those that are concerned with improving command and control and interoperability. In essence we can simplify these down into two key areas: simulation for training and simulation to support analysis and decision making. These two broad communities have very different requirements for their models and simulations. The training community requires models that exhibit credible and variable behaviour, related to the trainee with an appropriate degree of fidelity in real time. The analytical community is interested in the process and outcome of simulation runs, requiring repeatability and clear statements of assumptions and conclusions, very possibly in greater-than real time[15]. Figure 1 summarises the key requirements of HBR for each of the user groups.

Requirements of HBR for key user groups

	The Training Community	The Analysis Community
Requirements	BELIEVABILTY VARIABILITY VALIDITY OF ACTION AS PERCEIVED BY THE TRAINEE	OBJECTIVITY REPEATABILITY VALIDITY OF ACTION AS PERCEIVED BY THE ANALYST

Figure 1

It is important to note the issues of perspective raised, and their relevance for the modelling of decision making. For the trainer/trainee, entity behaviour should appear to be realistic from his perspective. Given that he will not be aware (with any degree of certainty) of the mission that the entity is conducting, it's particular situational awareness or a myriad of other factors that may affect it, this judgement can only be arrived at in broad terms. In essence, it is

[11] Where a synthetic environment is defined as "a synthesised representation of a common world which permits interaction between players". Definition courtesy of the Synthetic Environments Co-ordination Office (SECO), MOD.

[12] Ritter, "Techniques for modelling human performance in Synthetic Environments".

[13] Pew, "Modeling Human and Organisational Behavior", 44.

[14] Leonhard, "The Art of Maneuver", 141.

[15] Synthesised from p.13, Pew, "Modeling Human and Organisational Behavior".

impossible for the observer to validate the actions of the entity without placing them in the context of the entity's knowledge. However, the analyst using such simulations is going to need to satisfy himself that the entity's behaviour is consistent with its beliefs about the world. In other words, he must validate behaviour from the perspective of the entity. This is a much stronger condition. Petty[16], in looking at the suitability of a Turing-type test for CGF, concluded that assessments of validity of behaviour were not relevant for the training community in the light of the primary goal – the production of training benefit. However he concluded that such a test was of great importance for analysts, who had to have a great deal of confidence that entity behaviour was valid.

Key to our understanding of what will constitute a useful model is the purpose to which it will be put. In essence, we need to consider the defence context against which HBR must be viewed. In a recent supplementary review to Pew and Mavor, Ritter et al[17] state that "*the user community for synthetic forces would be better served if all these uses were supported by a single system or approach*". We would suggest that, whilst this may be a laudable aspiration in principle, it is unlikely to be realisable in practice in the near future[18]. As identified above, each of these areas will have different modelling and simulation requirements, hence placing different requirements on the representation of the human. It is surprising that there is, in essence, one effort to develop a useful general simulation of human behaviour rather than a series of efforts related to each of the requirement areas. Pew and Mavor acknowledge that "*given the current state of model development and computer technology, it is not possible to create a single integrative model or architecture that can meet all the potential simulation needs of the services*". In other words, different users need different CGF. This should be no great surprise; we would not try to use a model for some purpose that it is not appropriate or was not designed for in any other problem domain. Pew and Mavor go on to state that "*the modeler must establish explicitly the purpose(s) for which a model is being developed and apply discipline to enhance model fidelity only to support those purposes*"[19]. The authors would hence consider it an essential precursor to any model development to establish the specific needs of the problem domain. Further, we would consider it unlikely that a single model would have a span of applicability that transcends the problem domains identified above. We would therefore contend that distinct modelling efforts are required to develop suitable CGF models for each of the two key domains of training and analysis. In the former, the measure of success will be believable, credible entity behaviour as judged by the trainee from his perspective as an observer. In the latter, it will be judged on the repeatability and objectivity that the analyst can use to construct well-designed and meaningful experiments to inform studies and on the basis of credible and valid entity behaviour as judged by the analyst from the perspective of the entity.

Much of the research effort into HBR and CGF development over the past 10 years appears to have been dedicated to finding deliberative architectures that lead to rational decisions in a traditional knowledge engineering sense. This approach is sanctioned by Pew and Mavor who state that, "*(I)deally, individuals will exhibit behavior that reflects rational analysis and evaluation of alternative courses of action, including evaluation of alternative enemy actions, given the context*"[20].

However, whilst this may be a laudable aim for the analysis community, we suggest that low level combat is not a rational process. At the lower levels of combat, soldiers and vehicles rely greatly on practiced actions and drills in order to allay the inevitable confusion of battle. Decisions typical of this level have been termed Action First Decisions[21]. To a certain extent these do not qualify as decisions at all, in that they are more instinctive actions, or perhaps "compiled" actions, to borrow from expert systems terminology. They are a consequence of training, common sense or some other stimulus. In essence they are designed to ensure that the individual in some dangerous or threatening situation does not have to think what to do next. Further, individuals will reach different conclusions about the state of the battle based on their experience, situational- and environmental-awareness. This will in turn lead to the generation of different actions that may seem rational to the individual but are probably less so to an observer. Given that, in a training scenario the trainee is the observer, it is arguably impossible for the trainee to validate the behaviour of the entity. Our approach hence does not attempt to introduce independently validatable behaviors, but believable ones. It is hence a lesser requirement attempting to introduce an element of unpredictability into decision making that is currently not present in ModSAF.

In line with the above, this paper will concentrate on how CGF can better serve the training community. Training was the sphere in which CGF were first utilised and it is in this area that applications have undoubtedly had the greatest success so far. Hence we will concentrate on the requirements of trainees in real-time virtual simulations,

[16] Petty, "The Turing Test as an Evaluation Criterion for Computer Generated Forces".

[17] Ritter, "Techniques for modelling human performance in synthetic environments".

[18] As indeed Ritter et al go on to point out.

[19] Pew, "Modeling Human and Organisational Behavior", 2, 5.

[20] Pew, "Modeling Human and Organisational Behavior", 13.

[21] Basan, "A Framework for a Unified Decision Making Process".

almost certainly networked and distributed. In line with Pew and Mavor, we see the goal for CGF improvement in this domain to be that "*participants in real-time distributed interactive simulations will see the performance of individual soldiers and higher-level units in terms of the individual and unit behavior they exhibit, the execution of plans they formulate, and the battle outcomes that result. Although explanations of how the behavior comes about may be useful for after-action reviews, they are not needed during simulation execution. Only the outcomes need to meet the expectations of the audiences that will observe them. Similarly, detailed rationales for how groups accomplish tasks are generally irrelevant. What is important is that the group behavior mirrors that which is expected in the real world*"[22]. In other words, we wish to improve the believability of CGF in accordance with the expectations of the trainer and trainee.

ModSAF – The state of the art in CGF generation tools

There are several computer programs that are designed to allow the generation of CGF. The most widely used, and the basis for several planned packages[23], is Modular Semi-Autonomous Forces (ModSAF). ModSAF is "*a set of software modules and applications that construct Distributed Interactive Simulation (DIS) and Computer Generated Forces (CGF) applications entities used for realistic training, test, and evaluation on the virtual battlefield. ModSAF contains entities that are sufficiently realistic resulting in the 'illusion' that the displayed vehicles are being maneuvered by human crews, rather than computers*"[24]. It was designed as a research testbed for the development of CGF implementations for actual SE systems such as CTTT and the planned British version CATT. It is currently distributed to the authors as Version 5, and continues to be developed under the auspices and guidance of STRICOM. A full description of ModSAF can be found in the Functional Description Document[25] and the ModSAF Software Architecture Design and Overview Document (SADOD)[26], but a brief overview will be given here to place our planned work in context.

ModSAF claims to be able to "*replicate(s) outward behavior of units and their component vehicle and weapon systems to a level of realism sufficient for training and combat development*". Further, it goes on to claim that "*(T)he kinematics and dynamics of its vehicles cannot be distinguished by persons in manned simulators from those expected in manned simulators. The tactical behavior of all semi-automated units is designed to be doctrinally correct with defaults drawn from unclassified sources.*"[27]. Whilst the implementation meets its claims at one level of abstraction (the physical aspect of ModSAF entities mirrors that of manned entities in an SE exactly), it is widely accepted that ModSAF entities are less accurately represented in most behavioural aspects. For example, ModSAF entities do not have the appreciation of ground that leads to sensible and credible route selection. They need to be told exactly how to move in order to appear credible to the observer.

ModSAF consists of a set of software libraries and tools that allow the physical creation of entities within some virtual environment. The program is accessed through a user-friendly graphical user interface (GUI) which allows the rapid creation of entities and their tasking. There are a wide variety of types of entity that can be created in all combat domains. Further, users can define new entity types with relative ease (although ModSAF is a very complex system that does require considerable effort to become familiar with). Each entity type can be created as enemy or friendly forces. Further, entities bring with them a basic doctrine describing how the entity will react in certain circumstances along with other information such as standard ammunition carriage and weapon engagement ranges. Entities can be created individually or as organisations. In the latter case a command structure is created along with the entity that allows orders to be given to units and distributed to entity level.

Having created entities, the ModSAF user can then assign behaviours to them to meet the requirement of the SE that they are being used to populate. This is achieved through the generation and combination of entity tasks, again through a graphical user interface. Tasks govern the automated behaviour performed by a ModSAF entity or unit. For an individual entity such as a vehicle, example tasks might be vehicle move, avoid collisions with other entities, search for enemy vehicles, etc. In the case of a formed unit, such as a platoon, tasks might be unit movement or attack an objective, for example. These tasks can then be composed into task frames that define higher level activities. Task frames consist of a set of related tasks that run concurrently. An example might be moving whilst looking for enemy and being aware of what to do in case of contact - such a task frame might define a basic entity advance to contact. Task frames can then be combined sequentially to produce missions. Hence, ModSAF behaviours, observed through tasks, task frames and missions, are composed of relatively simple behavioural building blocks. These individual tasks are implemented within the program as finite state machines (FSM). Figure 2 relates tasks, task frames and missions as found in ModSAF.

[22] Pew, "Modeling Human and Organisational Behavior", 12.

[23] OneSAF, for example, is based on ModSAF.

[24] Science Applications International Corporation and Lockheed Martin Information Systems, "ModSAF 5", 1

[25] Science Applications International Corporation and Lockheed Martin Information Systems, "ModSAF 5".

[26] Lockheed Martin, "Software Architecture Design and Overview Document".

[27] Lockheed Martin, "Software Architecture Design and Overview Document".

Missions, Task Frames and Tasks in ModSAF

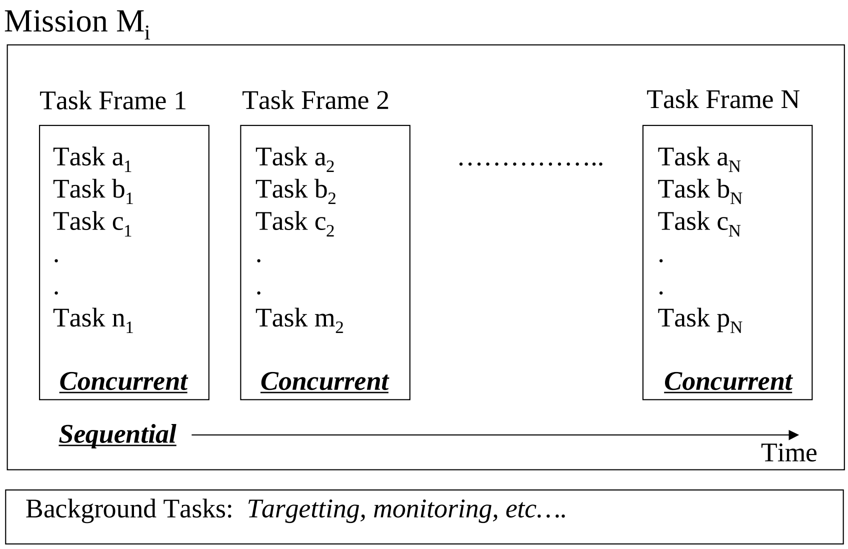


Figure 2

A FSM is a theoretical computer science construct that can be understood as follows. At any moment in time the machine will be in certain state. An input to the machine may cause it to change to a new state. The machine is called finite state because there are only a finite number of states that it can be in. In this context, then, we view a task (FSM) being conducted by a ModSAF entity as being in a certain state at a certain time (for example a background task to search for enemy). An input that is relevant (such as the detection of an enemy entity) may cause the task FSM to change state. In turn this may lead to the entity changing state (perhaps to some reaction to enemy drill). FSM are deterministic mechanisms, in that a machine in a given state will always do the same thing in response to a given input. Thus, ModSAF tasks in similar states will evolve in similar ways in reaction to similar environmental knowledge inputs or stimuli. In essence, then, it appears that ModSAF behaviours are scripted.

However, whilst tasks within ModSAF are deterministic, the evolution of a ModSAF scenario is not. Let us consider a simple scenario. Suppose that a single ModSAF entity is executing a task frame that consists of tasks T_1, T_2, T_3, ….,T_n (some of which may be background tasks). Let us say that some change in environmental information occurs (for example the detection of an enemy or the reduction of fuel or ammunition below some critical level). The first thing to note is that this event may be stochastic; enemy detections and the result of shots against targets are examples of this. This event acts as an input to the various running FSMs T_1 to T_n. Some of these tasks may change state as a result of the input. This may lead to conflicting requirements between the extant tasks. In this case there is a process called arbitration that balances competing objectives, allowing a decision to be made.

This scenario hence consists of effectively three types of process that together define the evolution of the state of a ModSAF entity or unit in the absence of interference from a human operator. To summarise, these processes are:

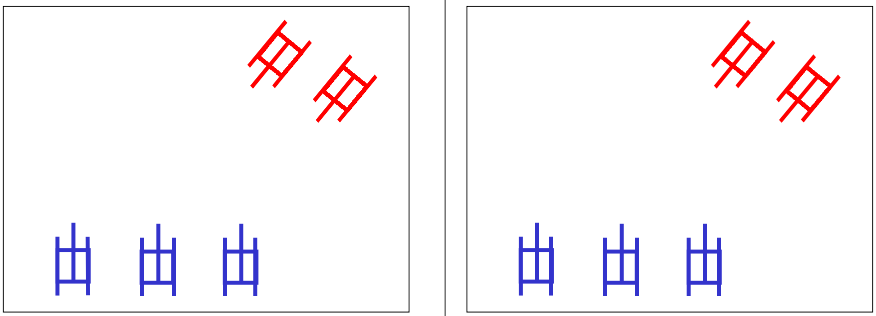
1. Generation of or change to environmental inputs. Environmental stimuli may be stochastic in that they are determined by sampling from probability distributions or other models (such as the detection of an enemy vehicle or the result of a shot at a target). Equally they may be pre-determined or deterministic in the sense that they are defined by the operator or the program (such as a point to move to or a level of fuel held by an entity). These environmental stimuli are the inputs to the tasks.

2. The evolution of individual tasks. Individual tasks will evolve as environmental knowledge is received. This process would appear to be deterministic.

3. Arbitration where tasks conflict in task frames. From time to time there may be conflicts between tasks within task frames. For example, a background task to monitor fuel supply may be triggered by the fuel reaching a certain level. This may trigger the task return to base. However the entity may also be engaged in a task to assault some location by fire, which obviously conflicts with the requirements of the other task. ModSAF will determine which task should be executed by the process known as arbitration. All relevant tasks will then be updated. Currently ModSAF uses a process known as mutual arbitration, where *"(E)ach task is aware of the requirements of the other tasks and the system is driven by consensus*[28]". This process would also appear to be deterministic.

[28] Lockheed Martin, "Software Architecture Design and Overview Document".

ModSAF	**Proposed CGF**



For each entity:	**For each entity**:
Behaviour - ***deterministic***, in reaction to battlefield and other events	**Behaviour** - ***stochastic***, in reaction to battlefield and other events
Battlefield events - stochastic	Battlefield events - stochastic
Other events - largely deterministic	Other events - largely deterministic

Figure 3

The state of a predefined ModSAF scenario would thus appear to evolve through a combination of stochastic battle events (detect, fire, etc) governed by deterministic behaviours. We hence have a strange hybrid where the uncertainty in the simulation depends solely on the outcome of battle events, but entities will behave in an identical manner in the receipt of identical environmental information. This architecture can, and has, lead to strange behaviours in simulations. These behaviours are well documented in the literature and reports such as Pew and Mavor[29] and can hence be taken as accepted for the purposes of this paper.

It would thus appear clear that, whilst ModSAF is an extremely useful tool in a variety of domains, there is a requirement to improve the representation of the human to produce a more realistic CGF. Our goal is to develop a method that can be bolted on to ModSAF to lead to a general improvement in representation. We will initially concern ourselves with behaviour at the entity level.

What we require in order to get more realistic CGF behaviours

Pew and Mavor[30] argue that improvement in realism in HBR will be achieved through three key areas. These are:

1. The establishment of a closer correlation between observed manned entity behaviour and computer-generated entity behaviour.

2. A reduction in the predictability of modelled forces.

3. An increase in the variety of observed behaviours "*due not just to randomness, but also to reasoned behaviour in a complex environment, and for realistic individual differences among human agents*[31]".

Prior to this they state that *"(i)t is important that observable actions be based on realistic decision making*[32]". Whilst this statement can be interpreted at several levels, it can certainly be taken to mean that entities take a more considered view of their actions and their consequences. Our thesis is that the architecture that we propose will take a step toward this goal, through:

1. Allowing the generation of individual entities that can estimate of their own survivability.

2. Allowing the generation of individual entities that each put a different value on the risk that they are prepared to take.

We would argue that such an architecture is going some way towards producing the reasoned randomness that Pew and Mavor have identified the requirement for. Whilst ModSAF offers deterministic behaviour generation with stochastic event determination, our model will allow stochastic behaviour generation and event determination, but in a sense that is in line with how real people make decisions based on perceived threat. The proposed improvements are best illustrated and contrasted in Figure 3.

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[29] Pew, "Modeling Human and Organisational Behavior".

[30] Pew, "Modeling Human and Organisational Behavior", 19, 20.

[31] Pew, "Modeling Human and Organisational Behavior", 20.

[32] Pew, "Modeling Human and Organisational Behavior", 1.

INTRODUCING MILITARY SCIENCE INTO CGF

Outline of approach

Very much in line with Pew and Mavor, we propose that the key for believable CGF development no longer lies in the domain of software engineering and development, but in the domain of sound behavioural and organisational modelling. As such a simple FSM based approach to the generation of behaviour can no longer be seen as being sufficient. The FSM approach implies that certain behaviours are always generated in response to certain environmental awareness. This approach is historical and deterministic, in that decisions are made on the basis of current and past awareness of the situation. In other words, no analysis of the likely implications of the current situation, in the light of individual missions, is conducted by entities at any level of sophistication. Some current thinking[33] views intelligence as an emergent property consequent on the interaction between entity and the environment in which it acts. ***Accordingly, the entities in traditional CGF are unlikely to ever exhibit intelligent behaviour (which is manifest through believability to the user) precisely because they fail to consider the consequences of their actions***. The basis of our idea is that the interpretation of entity situational awareness using the principles of what has become known as Combat Survivability Analysis[34] (CSA) allows entities to evaluate their actions against some notion of their own survivability. Our approach hence adds the dimension of possible futures which is currently missing from implementations of CGF such as ModSAF. In essence, we envisage simulations doing simple simulations of their own futures.

Outline of Combat Survivability Analysis (CSA)

Ball lays out the fundamentals of aircraft survivability in his book "The Fundamentals of Aircraft Combat Survivability Analysis and Design[35]". As the title suggests, the book is written with the air domain in mind, and one of the first tasks is to develop similar concepts for ground vehicles. In line with Ball's definition of Aircraft Combat Survivability we define entity combat survivability as ***the capability of that entity to avoid and/or withstand a hostile (synthetic) environment***. A related concept is that of susceptibility, which we define as ***the probability, P_{HIT}, that the entity is hit by some damage causing mechanism***. It is important to note that in all cases we are now looking at the environment as perceived by the entity in question. Let us now consider a simple scenario, which we will use to define our terms. Suppose that a single friendly entity is considering its susceptibility. At any instant in time we can consider its susceptibility as being divided into 3 different (sequential) categories:

1. Existence of Local Threat Activity. We will define the probability that threat activity exists locally to the friendly entity as P_{THREAT} .

2. Detection, Identification and Tracking. We will define the probability that the friendly entity has been detected, identified as hostile and is being tracked by another single enemy entity as P_{DETECT} .

3. Aim, Fire and Detonate. We will define the probability that the tracking enemy entity aims accurately, fires and that the round detonates correctly, causing a detonation event local to the friendly entity as $P_{AIM, FIRE, DETONATE}$. In fact we can view this as the product of the individual probabilities associated with three independent events, each with separate probabilities P_{AIM}, P_{FIRE} and $P_{DETONATE}$.

We are now able to write down an equation for the susceptibility of the entity in terms of the component probabilities as follows.

$$P_{HIT} = P_{THREAT} \times P_{DETECT} \times P_{AIM} \times P_{FIRE} \times P_{DETONATE}$$

We can now introduce a linked concept – that of vulnerability – again in line with Ball's definition for aircraft[36]. Let us define vulnerability as ***the inability of the entity to withstand damage caused by the hostile environment***. Vulnerability is measured as the probability of a kill occurring given a hit, and is written $P_{KILL/HIT}$. We now have

$$P_{KILL} = P_{HIT} \times P_{KILL/HIT}$$

In other words, the probability of a kill is the product of the susceptibility of the entity and it's vulnerability. We can then define the probability of an entity being able to survive the environment as P_{SURV}, where

$$P_{SURV} = 1 - P_{KILL}$$

Hence

$$P_{SURV} = 1 - \left(P_{THREAT} . P_{DETECT} . P_{AIM} . P_{FIRE} . P_{DETONATE} . P_{KILL/HIT}\right)$$

Further, given that several enemy entities may be in the vicinity[37], our entity faces threats from each and can calculate a probability of surviving with respect to each. It is tempting to suggest that these probabilities are independent, and hence can be simply combined to give an overall probability of survival. This is the line that Ball's analysis takes. But in the specific circumstances of ground combat we can observe that effective command and control will attempt to ensure that an enemy known to one entity is known to all, so that the events are not independent and the calculations become more complex. For the purposes of this paper we will hence only consider a one-on-one situation.

[33] Pfeifer, "Understanding Intelligence".

[34] Ball, "The Fundamentals of Aircraft Combat Survivability and Design".

[35] Ball, "The Fundamentals of Aircraft Combat Survivability and Design", 2

[36] Ball, "The Fundamentals of Aircraft Combat Survivability and Design".

[37] Or, indeed, that a single entity fires more than once.

Thus, given estimates of the various probabilities introduced above, the entity can estimate its probability of survival in any given set of circumstances. We have thus introduced an important new aspect into the generation of behaviour. Our entity is able to consider the threat that it believes itself to be under and act accordingly. In essence, it can now consider the consequences of its own actions in very simple terms. Current CGF implementations, notably ModSAF, do not appear to have the entities situated in the environment such that they will reason through the consequences of their actions in any way. Thus a ModSAF entity will make a decision based entirely on its historical perception of the world and on the “actions on” or reactions that it has been given. Our entity will consider what to do based on notions of its own survivability. In essence, our entity has become a simulation conducting simple simulations.

Using CSA to drive CGF behaviours

We plan to use the CSA results above to facilitate basic decision-making leading to the generation of behaviour in ModSAF entities. An outline of our proposed approach is as follows:

1. Allow entities to estimate the probabilities that they need to calculate their survivability as the battle evolves through the implementation of suitable models and tables.

2. Allow entities to generate individual survivability thresholds below which they will not go. This corresponds to the notion of it being too dangerous to continue on their current course of action.

3. Generate behaviour based on comparing calculated survivability with acceptable thresholds as the battle evolves.

Let us now elaborate on this process. Consider a running ModSAF scenario (that is a scenario with a number of entities, friendly and hostile, each with a set of tasks, task frames and missions). Now consider a single entity within this scenario. This entity has a state that is determined by its environmental knowledge (enemy and friendly forces that it is aware of, detonations that it is aware of, etc) and the tasks that it is conducting. Any change to the environmental awareness of the entity becomes an input to the FSMs that represent the tasks, leading to a change of task state and possibly to a change of entity activity. Our first premise is that,

given a suitable collection of models, lookup tables and distributions, the entity can associate an estimated probability of survival with the state that it is currently in.

Secondly,

any change in environmental information (such as the detection of a new hostile vehicle) will lead not only to the task FSMs being updated but also to an update in the probability of survival.

Thirdly, we would suggest that

each entity can have associated with it some notion of acceptable survivability, and that a comparison of perceived risk with acceptable risk can lead to the entity changing its activity through its tasks.

The combination of all these things is that we have an entity that is, to a certain extent, aware of its own state and hence future survivability and where individual entities have different "personalities" based on acceptance of risk. It does not seem unreasonable to suggest that such a CGF will be able to generate more complex - and possibly more believable - behaviours than the current tool. It is worth noting that what we propose does not alter the FSM nature of task generation – rather it provides a new environmental input to the model, which is the threat that the entity feels that it is under measured against what risk it is prepared to accept. It remains for us to suggest how we plan to implement these modifications in the existing tool.

The essential elements required in order to allow the generation of such an entity are twofold:

1. The ability to generate the individual probabilities identified above in order to estimate the overall probability of survival.

2. The ability to compare this probability with an individual risk aversion, generated by sampling from a probability distribution.

We now outline our current ideas for how these might be generated.

Probability generation and survivability calculation

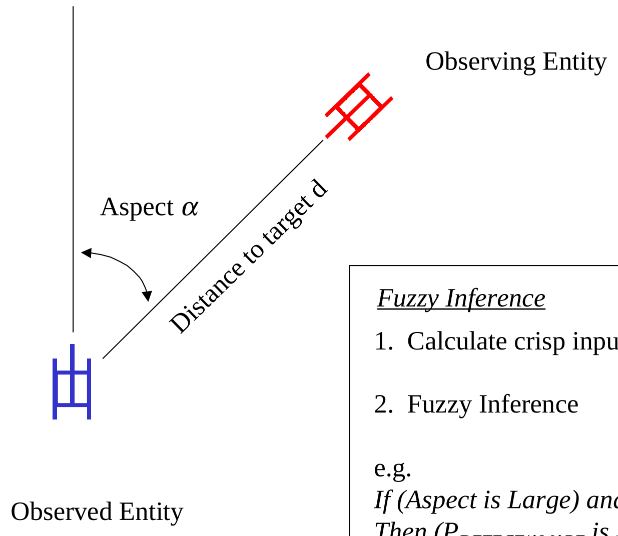
At any instant in time an entity will need to be able to effectively estimate the following probabilities in order to calculate its probability of survival in the current state: P_{THREAT}, P_{DETECT} , P_{AIM} , P_{FIRE} , $P_{DETONATE}$, $P_{KILL/HIT}$. The models used to generate these probabilities will, essentially, define aspects of the behaviour of the entity. Hence finding suitable models that produce realistic behaviour as judged by the trainer/trainee will form part of the experimental process. However, we now discuss how we currently feel that these probabilities might be obtained for the purposes of the paper.

1. $\mathbf{P_{THREAT}}$. The probability of a threat existing in the local area could be taken as being dependent on the task frames being conducted by the entity. For example, if the entity is engaged in an advance to contact it is reasonable to assume that the probability of a threat emerging could be taken as being unity. Equally, if the entity is (or becomes) aware of any enemy it should raise P_{THREAT} to unity. Having said that, if the entity is static in some position awaiting tasking P_{THREAT} may be lower than this. In the initial stages of experimentation at least it would not seem unreasonable to set P_{THREAT} to unity in all cases.

2. $\mathbf{P_{DETECT}}$. This is arguably the most complex probability to estimate. There are, in essence, two possible cases (mutually exclusive in the one-on-one scenario):

a. P_{DETECT} given that a single enemy is present and the observing entity is aware of him, which we will label $P_{DETECT/AWARE}$. We currently envisage that $P_{DETECT/AWARE}$ could be generated using the techniques of Fuzzy Logic[38]. For example, consider universes of discourse

[38] Zadeh, "Fuzzy Sets".



Fuzzy Inference

1. Calculate crisp inputs d, α

2. Fuzzy Inference

e.g.
If (Aspect is Large) and (Distance is Large) Then ($P_{DETECT/AWARE}$ is Small)

3. Crisp output of $P_{DETECT/AWARE}$

Figure 4

b. RANGE_TO_EN and ASPECT_OF_EN. Membership functions could be defined on each and a set of inference rules developed that allowed a link to a $P_{DETECT/AWARE}$ universe of discourse. Crisp input values for the range and aspect could then be used to generate a value for $P_{DETECT/AWARE}$ between 0 and 1 using Fuzzy Inference. Figure 4 illustrates the proposed process.

This mapping would, of course, have to be validated, which does present a challenge. However it is felt that a sensible mapping function could be arrived at by a judicious choice of membership functions. The model could be improved by including a consideration of such aspects as local cover, which could be catered for using fuzzy inference.

b. P_{DETECT} given that enemy is present and the observing entity is aware of him, which we will label $P_{DETECT/UNAWARE}$. Certainly in the initial trials it would seem reasonable to set this to zero whenever the entity is searching for enemy. A more sophisticated model might consider the area of ground that is currently visible to the friendly entity out to some range. The larger this area is, the greater the probability that there is an enemy out there that has seen our entity. Whilst this might be difficult to implement efficiently within ModSAF, it would be interesting to note whether entity behaviour changes greatly. One might hope that such an algorithm might give the entity an "appreciation" of ground, that is, a preference for cover.

3. **P_{AIM}.** We would suggest that the probability of a good aim being adopted by the enemy weapon system is largely a function of the range to target and the characteristics of the weapon system itself. For example, older weapon systems such as T55 tanks might not have as good fire control systems as newer models. This probability may hence vary from entity type to entity type and with range. Such a probability might be generated by a series of lookup tables.

4. **P_{FIRE}.** Again, this probability model could be taken at several level of complexity. For example, it is by no means determined that an enemy entity aware of our friendly entity will decide to fire on it – it may very well withdraw and observe for fear of itself being detected and engaged. Further, should the entity decide to fire it may in fact misfire. A suitable first iteration model would seem to be that the enemy decides to fire and has no misfire, which will be given by a probability of 1, but this can be developed further as with the other models to produce useful behaviours.

5. **$P_{DETONATE}$.** We would suggest that $P_{DETONATE}$ is largely a function of the ammunition being fired. Again, trials data and evidence may be useful here, but an initial model might be unity.

6. **$P_{KILL/HIT}$.** We would suggest that $P_{KILL/HIT}$ is a function of the vehicle doing the firing (or, more properly, the ammunition type) and the target vehicle. For example, a main battle tank mounting a 125 mm gun firing a high explosive round is likely to have a high probability of kill given a hit against a lightly armoured vehicle mounting a 30 mm cannon, such as a CVR(T). However, the converse is not true. Hence we suggest that this might be implemented using a lookup table or similar device.

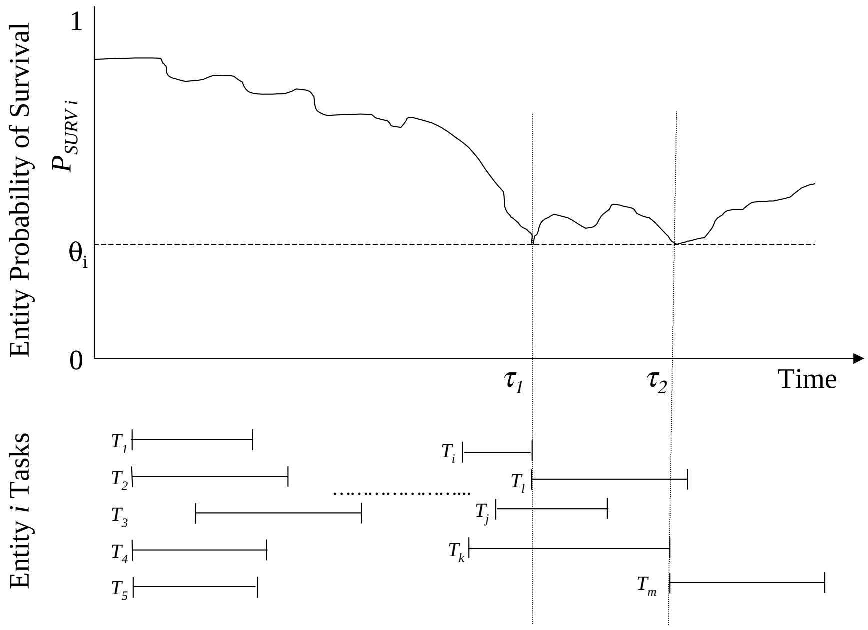


Figure 5

It can be seen that, certainly in the initial plans for probability models, the crucial models (and probably the most difficult to implement) are those for $P_{DETECT/AWARE}$ and $P_{KILL/HIT}$. Quite obviously, the success of the method stands or falls completely on the success of the probability models chosen, and this, together with their implementation in ModSAF, will form the majority of the work in this project. However, by the end of this stage the entity will be able to estimate its current probability of survival using some model of greater or lesser sophistication. The next stage is to introduce the notion of individuality based on aversion to risk.

Introducing personality by varying the acceptable surviveability threshold

Given an awareness of the risk associated with some particular task, a group of individuals will not, in general, agree on whether to accept the risk and proceed or to change the task to reduce the risk (if this is possible). In general, humans have different aversion to risk. This may not be, indeed, is unlikely to be, a purely rational process. Fear, for example, is highly likely to effect the decision-making ability of an individual. Bravery is seen by many as an ability to cope with fear. Real combatants are affected by fear in varied and unpredictable ways. The "flight or fight" mechanism is well known[39]. Equally, there are numerous examples of combatants failing to participate in battle, often meaning that a small proportion of the total force does the actual fighting[40]. However, current ModSAF entities are not effected by fear and hence do not suffer from these very human and very real failings.

A recent study[41] identified a way of simulating the aversion to risk of commanders by sampling from a probability distribution. The distribution was developed as follows. An experiment was conducted where a number of real commanders[42] were asked to assess risk in certain tactical situations and act accordingly. The data that the experiment provided was then grouped using a technique known as multi-dimensional scaling (MDS), which produced a two dimensional map grouping the data into classes. These classes were then used as the basis for the definition of fuzzy membership functions on a universe of discourse that represented a spectrum of aversion to risk. The result was a graph looking remarkably like a utility curve that could be viewed as a probability distribution of risk aversion in commanders. It was then possible to sample from this distribution using random numbers. This method thus makes it possible to generate commanders with an individual and specific risk threshold for use in simulations. At entity creation time each entity can thus be given its own aversion to risk that it will hold throughout the simulation.

[39] Grossman, "Defeating the Enemy's Will", 154.

[40] Marshall, "Men Against Fire", 78,79, suggests that only 15 to 20% of soldiers in combat will fire on an exposed enemy.

[41] Casey, "A Methodology to Produce Minefield Resource Planning Figures". This paragraph represents a distillation of some of this project.

[42] Students on the UK Joint Service Command and Staff Course (Shrivenham Phase)

Putting the two together

The general methods outlined above identify how individual entities may

1. Estimate the threat that they are under at any point in the simulation.

2. Compare this threat to their own aversion to risk, generated at entity creation time.

3. Take action accordingly.

We have outlined a plan of research to implement 1 and 2. We now need to briefly identify how this awareness of risk will affect what the entity does.

Let us assume that for some instant the entity is engaged on some task frame. It will be aware of its current probability of survival. Let us further say that this probability is above its individual risk threshold. Now suppose that, at some later time t, the probability of survival falls to below this level. From the entities perspective the risk of continuing on its current course is too great. It will thus change its course. At the current time we believe that each of the tasks that ModSAF entities can conduct needs to be examined to decide what the logical thing to do next is for that particular task. Thus, for example, if engaged on the task move a logical response might be stop, or perhaps seek cover and stop temporarily. If already stopped however, a lowering of the probability of survival might suggest that withdrawal is sensible. Thus each of the FSMs available to that entity will need to be examined and amended to accept a new environmental input – that of the probability of survival falling below the risk threshold for that entity. This will form another major strand of the research.

Summary of Planned Methodology

The process outlined above is shown in Figure 5. As each entity proceeds through the simulation it keeps and updates a record of the probability of survival at every moment. At each stage it will compare this with the risk threshold that is unique to it. At some time t it may find that the probability of survival is lower than the risk that it is prepared (individually) to accept, and it will take some action to change the tasks that it is currently engaged in.

Let us consider Figure 5 in a little more detail. At the start of the simulation our entity *i* is created with its individual aversion to risk, θ_i. At each point in time during the simulation (the simulation will proceed in discrete time steps, but we can show a continuous curve without it being too misleading) the entity is aware of the probability of survival. During the simulation it will be executing a series of tasks – background tasks and those organised into task frames and missions. At two points in Figure 5 the actual probability of survival falls to the threshold value. This occurs at the times τ_1 and τ_2. At these times our entity will look at each of the running tasks, and may change state in some of them. Equally, this new information may initiate new tasks designed to lower the risk, such as a withdrawal or a seek cover task. Thus at time τ_1 task T_i is halted and task T_1 commenced. These changes occur due to the introduction of what is in effect a new environmental variable – a need to reduce the risk of being killed.

It is worth noting that we hope that there will be at least two consequences of the introduction of a technique of this kind.

1. We hope that there will be a change in individual behaviours, resulting in a less scripted appearance and less uniformity of behaviour within units, in line with realistic combat behaviour.

2. We hope that the consequence of linking lots of entities with these kinds of capabilities might lead to interesting emergent properties in the simulation as a whole due to the interactions.

Our research is now aimed at implementing this method to ascertain whether or not 1 and 2 above are true and whether or not there is any discernable improvement in training benefit.

CONCLUSIONS

We believe that the current generation of CGF tools is insufficient for training soldiers in the way that they aspire to fight. A methodology is proposed that uses the principles of CSA to introduce notions of individual risk to entities. Further, entities can make decisions about their actions based on this risk and an individually generated aversion to risk. We hope that the methodology we have outlined will prove useful in giving more realistic behaviours in CGF, hence allowing trainees to get greater training benefit from the use of simulations. The research programme outlined will attempt to show this to be the case.

The British Army has adopted, as have other NATO armies, a manoeuvrist approach to warfighting. This approach aims to create the psychological conditions for defeat in the minds of the enemy by attacking his cohesiveness and morale. It aims to avoid destructive attritional battles, but to defeat the enemy by pre-emption, dislocation and disruption. Thus our basic warfighting philosophy concentrates on attacking the human spirit and creating fear and indecision in the mind of the enemy. Despite the best efforts of researchers, current HBR models implemented in CGF do not allow the creation of an enemy with these vulnerabilities. It follows that considerably more creative effort must be invested in the quantitative examination of human phenomena and their effects on the conduct of battle. Until human behaviour can be modelled more successfully we will be unable to train for manoeuvre warfare using these tools. As Leonhard has stated, *"(w)hile computer modelling has the potential to add significantly to our study of warfare, the models and scenarios - indeed our whole approach to simulation - restrict the effectiveness of these remarkable tools. It is thus as important to recognise the limitations of simulation as to appreciate the possibilities* *offered*"[43]. This work aims to reduce the limitations and increase the possibilities for the use of CGF in training simulations.

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[43] Leonhard, “The Art of Maneuver”, 137

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Exercise - ‘Réaction Combinée’

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A Simulation Framework for Command and Staff Training

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Keywords:
Simulation Architecture, Multiple Force Representation, Operations Other Than War, High Level Architecture, Agent Architecture, Terrain Generation

ABSTRACT: *Military operations occur within a wide spectrum of situations including force on force operations (e.g., Grenada), large coalition operations against an enemy force (e.g., Desert Storm), peacekeeping operations as part of an international peacekeeping force (e.g., Bosnia), etc. Each of these situations has a unique set of forces and sides that are involved including, but not limited to: the US military, the enemy force, allied coalition forces, non-combatant civilians, non-governmental organizations, etc. In addition, each requires development of geo-specific databases of the area of operation. The process for constructing, controlling, and reporting on these forces in legacy constructive simulations is typically a labor-intensive, expensive operation. This presentation will describe enhancements in such areas as force laydown, terrain generation, unit control via agent architecture, and after action review (AAR) that provide the potential for more realistic portrayal of military operations at a fraction of the training cost. The approach and results of a proof of principle integration of Warfighter Simulation (WARSIM) software within a simulation framework will be discussed and demonstrated via DVD video segments.*

Speaker's Biography

Colonel Ball was born at Camp Kilmer, New Jersey. He graduated from the Citadel in 1976 with a Bachelor of Science Degree in Mathematics and was commissioned a Distinguished Military Graduate through the Reserve Officers' Training Corp. Following the Military Intelligence Officer's Basic Course he reported to Berlin, Germany where he served as the Management Information Systems Officer for Field Station Berlin.

In 1980, following attendance at the Officer Advanced Course, he was transferred to Fort Riley, Kansas where he served first as the Division Intelligence Analysis Center Chief, then as Opposing Forces Commander and Division Simulation Center Deputy, and finally as Company Commander for the 1st Infantry Division Headquarters Company. After attending the Combined Arms Services Staff School (CAS^3) he was transferred to the National Security Agency (NSA) at Fort Meade, Maryland in July 1984. There he served as a Senior Intelligence Collection Manager for one year before being selected to attend NSA's Junior Officer Cryptologic Career Program (JOCCP). While there, he was awarded a Master of Science degree in Computer Science from Johns Hopkins University and completed both Command and General Staff College and Air Command and Staff College non-resident courses. At the completion of JOCCP in July 1987, Colonel Ball was selected to study at the Massachusetts Institute of Technology's Artificial Intelligence Laboratory as an Army Visiting Scholar. In July 1988, he was transferred to Fort Huachuca, Arizona where he served as Chief of the Intelligence School's Artificial Intelligence Laboratory. While there, he deployed to Desert Shield/Storm to support VIIth Corps.

In August 1991, Colonel Ball was transferred to Washington DC to support the integration of technology tested during Desert Storm into the All Source Analysis System by serving as the Deputy Product Manager for Single Source. In July 1993, after attending the Program Managers Course at the Defense Systems Management College, he was assigned as Chief of the Sensitive Records and Information Agency working for the Vice Chief of Staff Army. Colonel Ball assumed his current position as Project Manager, Warfighters' Simulation on 24 June 1999 after graduating from the US Army War College.

His awards include the Defense Meritorious Service Medal, The Army Meritorious Service Medal (with one Oak Leaf Cluster), the Joint Service Commendation Medal, the Army Commendation Medal (with two Oak Clusters) and the Army Achievement Medal.

Colonel Ball is married to the former Debra Carter of Parthenon, Arkansas. They have one son, Jonathan.

Presentation Script

Slide 1 -

Good morning, I'm Colonel Randy Ball, the Project Manager for WARSIM – The Warfighter's Simulation 2000. Today, I will give you a brief introduction to WARSIM, the US Army's next generation aggregate constructive simulation.

Slide 2 –

I'm going to cover the listed topics, starting with some explanation of why we need a new simulation, then proceed to give you some flavor of what we are trying to build, highlighting the significant changes from our existing simulations. Then I'll segue into a description of some of the key technologies that will enable WARSIM to become a reality. Finally, to convince you that this is not just smoke and mirrors, I have some video clips of WARSIM operating. I'll use these to highlight some additional features of WARSIM.

Slide 3 –

However, before starting, let me give you some insight into my responsibilities as PM WARSIM. Fundamentally, I am the material developer for all of the Army's training related constructive simulations, both current as well as those under development. This graphic shows our migration strategy from the legacy simulations, primarily CBS, JANUS, and BBS, to our future simulations WARSIM and OneSAF. Of particular note is the Army's requirement to support command and staff training for our emerging digitized force structure, thus the requirement for digital interim tools such as our Digital Battlestaff Sustainment Trainer (DBST) as well as the Run-Time Manager (RTM) adjunct to CBS and BBS which permits those systems to support digital training. My job then, is to ensure the availability of simulation tools that enable US Army command and staff readiness while completing the development of our future tools.

Slide 4 –

Now that you know what I'm all about and my primary missions in life, let me give you the high points about WARSIM - and I will come back to these later as well… In fact, if you remember nothing else about WARSIM, don't forget these points.

First, WARSIM is primarily designed to train Commanders and their staffs at the Brigade and above levels, including commanders of Joint/Combined Task Forces. Our future simulation for lower echelons is OneSAF.

Second, WARSIM will allow, no force, commanders and staffs to train the way they will fight, by using their organic command and control systems. In addition, WARSIM will permit them to operate in a tactical environment, removed from a fixed site or simulation center.

Third, WARSIM represents a quantum leap in simulation fidelity for exercises of this size. WARSIM will enable our doctrine, tactics, techniques and procedures to be fully employed and show the requisite results in the form of combat outcomes.

Finally, and potentially most importantly, WARSIM will represent all levels of conflict from high intensity to Stability and Support operations like Bosnia and Kosovo. Over course of the briefing, I'll highlight more details on each of these points.

Slide 5 –

Now, you may be asking why all this is necessary so let me take a few moments to explain. As you are all well aware, the nature of the world has changed dramatically since the end of the Cold War resulting in a completely new battlespace both from an operational and training standpoint.

Commander's today enjoy a substantial ability to precisely see and strike at extended ranges, but they lack the calibrated ranges needed to develop, practice, and refine precision warfighting tactics, techniques and procedures.

Facilitating that ability to precisely see are support organizations that operate from sanctuary in real-time, however commanders have few if any venues, other than learning during an operation, by which they can discover and leverage the full range of supporting organization services.

Even live-training at the National Training Center, our crown jewel, is affected. Brigade areas of operations have outgrown even the 60x60km NTC, and we're now seeking something on the order of a 300x300 box for single echelon training for our Force XXI digital units. The full range of national, theater, and tactical sensors, so critical to our current warfighting doctrine, are far too expensive for live training.

Finally, since 1990 the US Army has been involved around the world in numerous operations, only one of which remotely resembled the land battle for which we prepared during the Cold War era. Commanders and staffs require the capability to train for all the missions in which they might be involved.

The solution is simulations. Unfortunately, our training simulations have not kept pace. Designed and perfected during the Cold War, our current simulations have neither the flexibility nor the breadth required for the world today.

Slide 6 –

Thus WARSIM. In WARSIM we are developing the integrated, extended battlespace commanders can seldom afford in training, but likely will face in war.

Some of WARSIM's key features are listed on this slide. I don't have time to discuss each one, but let me cover some of the key points.

WARSIM will enhance realism for the training audience in a number of ways. First, as I have highlighted before, it will support the full spectrum of mission operations in ways never before possible. In fact, its architecture and design will even permit us to train commanders and staffs in the employment of both offensive and defensive information operations. The synthetic environment, being developed in coordination with the Combined Arms Tactical Trainer, provides an unprecedented level of detail for a Corps/Division level simulation and will facilitate the virtual to constructive linkage. Finally, WARSIM will provide a first ever bi-directional linkage between the Commander and staff and the simulation using their organic C4I devices.

Another important feature of WARSIM will be the reduction in staffing required to conduct exercises. A Corps level exercise today requires hundreds of support personnel and role players. Our objective is to reduce this number by two thirds. Achieving this goal is critical, in part because of our discoveries regarding the perishability of the skills required to effectively operate the C4I systems thus driving the need for more frequent exercises. Some of WARSIM's most important features are "under the skin". Developed to the standards shown, in a modern object oriented architecture, WARSIM will in fact be the Army's simulation of choice for the next 20 years.

Summarizing, WARSIM will closely replicate the lethality, stress, and complex interactions of the current and future battlefield while increasing the commander's flexibility and available resources for training.

Slide 7 –

With the "why" and the "what" covered, lets spend some time on the "how" of WARSIM.

I haven't explicitly mentioned JSIMS - the Joint Simulation System - previously so let me digress for a moment. As many of you know, WARSIM does not stand alone. In fact, we are depending upon the JSIMS alliance to provide the core architecture required for WARSIM to operate. I've use the following metaphor with many of my bosses. "WARSIM is the tank, JSIMS is the engine"

JSIMS is a new development, just as WARSIM, driven by many of the same reasons I've already described as well as many others related to problems with its predecessor, the Joint Training Confederation. While I don't have time to list the problems, the fundamental goal of JSIMS is to provide a single, consistent, common battlespace to support all our service, joint, and combined training requirements.

JSIMS will consist of a number of Common core components used by all developers including a simulation engine, the synthetic environment, a common user interface supporting scenario generation, exercise control, exercise operation, and after action review. All these pieces will be linked using the High Level Architecture Run Time Infrastructure (HLA RTI) and will use a single Federation Object Model.

Each Development Agent will provide accredited functional models for its own domain, thus WARSIM is providing all Land Warfare models. In addition, WARSIM is providing the Synthetic environment for the entire alliance as well as the tactical intelligence model.

Slide 8 –

This slide describes some of WARSIM's capabilities at IOC. Let me just highlight a few that I won't be covering in the following slides. Each of these capabilities represents significant advances over our legacy systems.
Of particular note is WARSIM's choice for level of aggregation. Where CBS was aggregated primarily at battalion level, in WARSIM units are modeled at the equipment group level, nominally platoon level, although for specific circumstances equipment groups can contain as few as one vehicle. This level of fidelity is required to support our maneuver and synchronization doctrine. Concurrently, WARSIM is introducing radical changes in the direct fire model which are also required to support our maneuver doctrine. Most significantly, WARSIM is implementing both geometric and probabilistic line of sight. In addition, direct fire engagements can be modified by attributes associated with each equipment group including weapons control status, target priority lists, engagement areas and sectors, restricted fire areas, fire thresholds, and the enemy force types. Complimenting these enhancements is the Battlefield Outcome Adjudicator or BOA. BOA is a rule based expert system that provides additional modifiers to combat accounting for factors such as morale, level of training for a unit, fatigue, or even PSYOPS.

WARSIM's implementation strategy using modern object oriented development and data driven behaviors is key to implementing new functionality as well as ensuring long term viability. Object-oriented code will make WARSIM more maintainable and supports more simplified addition of new functionality. Data driven behaviors will permit user's to make changes on the fly, adapting to both emerging doctrine and providing the ability to modify existing behaviors to replicate new threats. When fielded, threat behaviors in WARSIM will be modified versions of the same behaviors we are developing for US units.

These direct fire and behaviors enhancements will be nothing if the user cannot interact with the simulation in the same manner in which he would operate in conflict - thus the "train the way you fight" requirement for our simulations. WARSIM will provide bi-directional interface with US command and control systems such as ASAS, AFATDS and MCS. Previous simulations have provided one-way interfaces, providing common operational picture and intelligence data with limited capability for the user to impact the simulation without the assistance of a role-player. The bi-directional interface will permit a user on an MCS or other C4I device to generate an order to a unit within the simulation. The simulation will then parse and execute the order, conducting a replan if necessary and report results and status back to the user, just as a real unit.

Logistics fidelity will also be quantum improvement over our current simulations. To implement high-fidelity logistics model today requires federating with a special purpose simulation, thus logistics play and its impact on the battlefield is often ignored during exercises. In WARSIM, high fidelity logistics will be integral to every object. For example, each unique equipment type will have 15 different spare parts which could be requisitioned to support repair. The entire supply chain will be modeled, and logistics units will be integral to the battlespace and as such will be susceptible to the same actions as any combat unit. For example, a resupply mission is susceptible to interdiction by air, artillery or direct fire. Successful interdiction will have the appropriate impact on the simulated battle, I.e. the unit being resupplied will run out of beans, bullets, gas, or repair parts and potentially not be able to conduct its assigned missions.

Key to facilitating training is the ability to provide detailed after action review data in forms that facilitate the process. In our current systems, AAR data collection is an add-on. In WARSIM, AAR capability is being designed in from the start, from inclusion of specific fields in objects/models to our user interface. In fact, one design consideration for WARSIM has been the requirement to pass all communications supporting an exercise through the simulation. Exercise directors will even be able to capture the voice traffic on command nets for inclusion in the AAR process.

Slide 9 –

Some of the most revolutionary capabilities of WARSIM will be enabled by the extensive use of automated behaviors. Contrasted with the legacy CBS where humans make virtually all the decisions, in WARSIM role player intervention will be the exception rather than the rule.

Our implementation of these behaviors is worthy of another stand-alone discussion, but given my limited time, let me describe just the basics. We are implementing behaviors using an agent-architecture based simulated command organization combined with a military behavior specification language. For our initial version, we will implement SCOs and behavior definitions for all 111 company level tasks as well as commonly used battalion level tasks. Some examples of battalion level tasks are road_march, move_tactically and defend. To reach our goal of two thirds reduction in role-players, we will eventually develop behavior definitions for all battalion level tasks as well as most brigade level tasks.

The simulated command organization consists of a number of agents that somewhat replicate the functions performed by a commander and his staff, including and estimator, planner, coordinator, executor, and distributor. The agents operate on a world model that represents perceived truth for that command organization that is formed from the intelligence received by the unit as well as the reports from subordinate, superior and lateral units. One implication of this model is that WARSIM will force commanders to employ intelligence to develop an accurate “perceived truth” and corollary to that is the possibility for deception operations. The distributor agent is responsible for most C4I interface actions within WARSIM, determining what messages need to be sent and to whom.

The flexibility and power provided to WARSIM by these SCOs is such that we intend to use the same structure for our new entity level simulation: OneSAF.

Slide 10 –

One overarching concern with the current Joint Training Confederation is the disparate simulated environments used by each system. These disparate environments cause numerous problems, not the least which is the ability to ensure a “fair fight” amongst all players. As a result, the entire JSIMS alliance will use one Synthetic Environment, referred to by us as the SNE. In development since the inception of JSIMS, and standing upon the lessons learned by many previous programs (including CBS, ModSAF, and CCTT), the foundation of SNE is the Terrain Common Data Model. This model defines all the terrain features and attributes required by JSIMS. It is currently being extended to include features and attributes required for our virtual simulations as well as OneSAF. Elevation data and surface areal data is being encoded using triangular irregular networks or TINs. For JSIMS and WARSIM, we are developing data sets equivalent to approximately 1:100000 scale operational maps.

We are providing access to the datasets by developing application program interfaces (API) that support route planning, query about terrain features, line of sight calculation, and many other functions. In addition, the SNE will support dynamic terrain. For example, bridges are a feature type in the SNE. Model interactions with the SNE will be able to cause the destruction of a bridge and subsequent changes to results returned from functions such as route planning.

Concurrent with development of the SNE, we are attempting to resolve another critical problem. The availability of natural environment databases to support simulations is problematic, largely because of the inordinate amount of time required to correct the intrinsic problems in the source data. We are developing a suite of tools that, subject to availability of source data, will permit development of a simulation terrain database capable of supporting a Corps level exercise in only two weeks, vice the 3-6 months required for the same effort today.

A couple more points about our synthetic environment are in order. Lest you think we are only developing this SNE for land, remember the J in JSIMS. The TCDM includes features and attributes critical to all members of our alliance including littoral and subsurface sea features as well as sea and atmospheric states. Initially the SNE will provide limited weather state information, but we will be adding more dynamic weather as we continue to develop JSIMS and WARSIM.

Slide 11 –

Given the availability of more detailed terrain, let me describe in a bit more detail how we will use it specifically with regard to sensing.

Sensing is conducted at the equipment group level and starts with calculation of geometric line of sight. Given that LOS exists, modifiers are applied to determine acquisition level if any. Modifiers to sensing include environmental conditions, and characteristics of both the sensing and target units. Of note, the SNE supports probabilistic line of sight, or the concept that one might be able to see through a stand of trees, depending upon their height and spacing. Positive sensing results in acquisition at one of four levels: detection, classification, recognition, and identification.

Slide 12 –

Given our current and emerging doctrine, one of the most important advances being provided by WARSIM is the greatly enhanced intelligence modeling. The WARSIM Intelligence model in concert with theater and national models being provided by other JSIMS partners will give our users unprecedented intelligence fidelity.

Combined with that flexibility will be the requirement to fully exercise the intelligence process in order to get the desired information out the back end. No longer will commanders and staffs receive perfect intelligence from the simulation. Commanders must clearly define their intelligence requirements and their staffs must convert those requirements into executable collection plans with appropriate tasks to available collectors. Intelligence is modeled as an interconnected system of systems. If all the piece parts are not in place and executing correctly, the required intelligence will not flow to the commander.

WIM will portray all tactical sensor models including imagery, signals intelligence, human intelligence and MASINT. Of note from an imagery perspective will be support for both JSTARS and UAV. The UAV capability (some samples of which are included in the upcoming video clips) combined with other intelligence assets will permit commanders to exercise TTPs such as cross-cueing and sensor-to-shooter with assurance of success if executed correctly. This represents a significant change from our past capability and is possible only because the common synthetic environment and the fidelity of WARSIM models.

Another major enhancement in WIM is HUMINT which includes counter-intelligence/HUMINT teams, interrogation of POW, and long range surveillance teams. This HUMINT capability will facilitate WARSIM’s ability to support stability and support operations.

One other note regarding intelligence. In our existing simulations, intelligence assets are typically not a part of the gamespace. In WARSIM, our tactical intelligence models will be attached to actual units and equipment in the gamespace. For example, WIM’s airborne sensors will be attached to aircraft models being developed by JSIMS Air Force partner. These models will be in the gamespace and thus be subject to the same threats as any other aircraft (including weather).

Slide 13 –

Finally, as I have alluded to previously, WARSIM will provide significant simulation capability to replicate and train for non-traditional operations such as Bosnia. This capability is actually a twist on other functions already implemented in WARSIM combined with the fact that WARSIM will support up to ten different “sides”, each having a different friendly/hostile/neutral orientation to each of the others. This orientation is not symmetrical in pairwise relationship, so it will be possible to conduct exercises where on side is neutral or hostile to a side which is friendly to it, allowing for some interesting possibilities. WARSIM’s ability to support multiple force alignments combined with behaviors such as weapons control status, target priority lists and engagement areas will permit support for a broad range of operational scenarios.

Now that you have some familiarity with WARSIM and its planned and existing capabilities, lets move on to several short video clips of WARSIM in operation. These scenarios will display many of the capabilities I’ve described to you.

Slide 14 –

Our scenario is set in SW Asia; OPFOR units have deployed along and south of a recently established truce line. U.S. and Coalition forces move north to restore the truce line.

This vignette demonstrates the exceptional flexibility that the exercise director has in scenario generation with respect to creation of multiple force types with doctrinally correct data driven behaviors. Force orientations (friendly, neutral, hostile), universal systems (complete flexibility in employment of any combat systems in any force type), and a variety of rules of engagement allow an exercise architecture readily configured to the full spectrum of mission requirements (stability and support operations, small scale contingencies, major regional conflict, major theater of war). Intel sensors (JSTARS, Guardrail, ARLM, and UAV – ELINT/IMINT systems) hosted on Air Force and land combat platforms support the Coalition move north and directly stimulate C4I systems in a two way interface with the C4I systems deployed in the training audiences' TOC.

All exercise participants benefit from the same gamespace representation generated by a common synthetic natural environment.

In this scenario, as Coalition elements (modeled as Initial Brigade Combat Team and conventional U.S. forces) move north and OPFOR units withdraw across the truce line, there is, at this point, no combat.
We now transition to a view of the Maneuver Control System (MCS) showing current BLUFOR locations automatically updated from simulation generated location reports. MCS also shows known enemy locations sent from the All Source Analysis System (ASAS).

In the video we briefly show the message log indicating incoming location reports and outgoing orders. We also briefly show the frag order format used for the order sent to the workstation controller to initiate the movement to contact which sent the BLUFOR units north.

This picture-in-a-picture highlights the initial known versus unknown enemy locations. Intelligence modeling ensures intelligence sensors and organizations operate according to the same "move, shoot, and communicate" rules as their combat model hosts. This feature assures commanders practice wartime planning and execution tasks, and only receive intelligence their architectures and efforts can reasonably support.

ASAS shows a subsequent, more developed picture of the enemy. This image shows the close battle situation complemented by deep battle reports of a radar site and reinforcing armor company. This information comes from the employment of a Guardrail ELINT sensor and UAV IMINT platform, and subsequent ASAS receipt and parsing of the TACELINT and RECCEXREP reports, respectively. In response to this threat, the commander directs the UAV recon focus on those units.

Slide 15 –

This next vignette takes us from the initial force projection stage into a sequence of activities leading up to conventional conflict. The exercise director has the ability to control precisely when and where combat events will be initiated through flexible rules of engagement. In order to exercise the training audience in support of their mission requirements, the director can present a series of events as decision points.

In this scenario, the exercise director has orchestrated the "surrender" of a platoon-size element (OPFOR unit was work station transferred to BLUFOR controller). As that EPW is escorted to the rear for HUMINT interrogation, an OPFOR unit in the Coalition sector on the west flank initiates a direct fire engagement. Coalition response is specifically controlled by rules of engagement, with, in this case, no damage done to the Coalition unit and no fire returned.

As these actions occur, an OPFOR unit on the east flank moves south with no indication of surrender (no workstation transfer of control); this serves as a provocative gesture.

The exercise director, with multiple force types and an array of various rules of engagement may pose any number of incidents to assess training audience reaction. In this scenario, commensurate with the provocative move south, the commander orders the U.S. and Coalition forces to attack.

The attack initiates with indirect fires representing those directed by automated behaviors – artillery units in direct support of attacking elements fire automatically against sensed enemy which meet engagement criteria of target type and echelon. Role player directed fires supplement the automated fires. Direct fire is automatic in accordance with the rules of engagement.

Slide 16 –

This vignette further displays the precise representation of units in the common gamespace and precision intelligence capabilities.

As the ASAS discussion earlier identified armor and ADA elements as potential deep targets, the commander directed the UAV to provide coverage of that area. In this vignette we see the initial footage of the UAV visualization provided through WARSIM to the commander's TOC. As the UAV closes on the target, the commander is able to identify T-80B armor systems and surface to air missile systems.

The simulation role player at the battle simulation center only sees the icon representation on his screen. The UAV visualization is not available to the role player. The role player controls the deep attack in accordance with the orders sent from the training audience in the field. The role player must use sound tactics to ensure the aircraft approach the target making the best use of terrain and weapons standoff capabilities. In WARSIM the aircraft must have line of sight to sense the ground target, and, if the aircraft close to small arms range of the target, they will be engaged by tank main gun. Small arms in the air defense role is a significant asset in WARSIM, helping to ensure appropriate tactical employment.

As the aircraft engage the armor systems, the UAV visualization depicts the ground systems precisely where they are in the game space. If there were a SCUD in the target area, and the commander had precision assets, he could target directly from the UAV visualization data.

As the damage state changes to catastrophic kill, the UAV image indicates the status by displaying the flames and smoke. Those armor systems engaged and damaged will be engaged again until destroyed or until mission termination for the aircraft. Those armor damaged but not destroyed show no indication in the visualization. As the final volley of missile fire engages the remaining armor systems, all tanks in the target area are destroyed.

The final scene shows the UAV capture of the overall target area with two of the Apaches departing to the west. This capability allows immediate battle damage assessment by the commander.

Slide 17 –

The SASO scenario reinforces the demonstration of the flexibility and control the exercise director has in orchestrating training. This scenario involves six different force types representing refugees, U.S. Marine security elements, U.S. Army units, OPFOR elements, host nation support elements associated with an international relief organization, and hostile indigenous forces. They are controlled by role player input and database driven, doctrinally appropriate behaviors constrained by rules of engagement.

The scenario initially focuses on refugees and a SPF team to the east. Intelligence systems (UAV and ARL-M) have identified the SPF and the refugees. The SPF team is a direct threat to U.S. and allied forces. The refugees pose a threat to movement of a host nation support convoy.

The SPF element is addressed through air assault of two squads of U.S. Marine security to destroy the OPFOR unit.

The training audience responded to the refugees by sending host nation security forces and a U.S. psychological warfare unit to control the refugees (workstation transfer of the refugees by exercise control rewards the training audience response to the refugee situation).

As the training audience deals with the SPF team and the refugees, a terrorist element (single vehicle, target priority of aviation) moves toward the airfield. This threat will be addressed by a U.S. Marine security unit as the Marine unit senses and identifies the terrorist as hostile.

Finally, we transition to the hostile indigenous element as it closes on a military police unit. This hostile element will pass a U.S. Marine unit and two neutral elements without firing. It engages only the U.S. MP unit. The U.S. military police unit responds by withdrawing (role player directed in accordance with training audience direction) out of weapons range but between the hostile indigenous element and the airfield. The military police do not return fire; however, their rules of engagement could be modified to have them engage. This serves to further reinforce the discussion of control the exercise director has to create an exercise architecture with whatever force types, force orientations, and rules of engagement he requires to train throughout the full spectrum of his mission requirements.

Slide 18 –

That's WARSIM as it exists today how it will exist in the future. Before I close, I'd like to leave you with these key points - and I did tell you that you would see them again.
WARSIM will train Brigade through Corps level commanders and staffs. It will require them to train the way they will fight, fostering leader development through its fidelity and representation of the battlespace, and it will support all the missions which we foresee executing.
WARSIM, combined with OneSAF will be our tool for training commanders and staffs for the next 20 years.
Subject to your questions, that concludes my briefing.

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UK Future Offensive Air System (FOAS): From Requirements to Operation

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ABSTRACT: *As Synthetic Environment (SE) technology continues to mature, a pattern is emerging for utilising SEs. As part of the concept analysis stage of the Smart procurement cycle, the Future Offensive Air System (FOAS) Integrated Project Team (IPT) at the Defence Procurement Agency (DPA) has defined, developed and employed an SE to complement the more traditional analysis work required for submission to Initial Gate.*

A collaborative partnership has been established between DPA, the Defence Evaluation & Research Agency (DERA) and a number of Industry partners to design, implement and operate the FOAS SE. The primary aim has been to support the FOAS concept analysis for various force mixes. However, the SE has been designed with the deliberate intention of providing a re-usable facility for future investigations, and has drawn strongly from experience of many previous SE areas, such as the Air Defence SE (ADSE), FlasHLAmp and the Synthetic Theatre of War (STOW) programmes. In this context, the design of the SE employs a standards-based framework in accordance with the US High Level Architecture (HLA). The implementation of this SE has also been underpinned by the integration of commercial off-the-shelf software tools, aimed at addressing SE management and control issues.

This paper provides a position statement on the development and use to date of the SE for FOAS analysis, and captures the lessons learnt. Also discussed are the management processes used to define, implement and operate the SE, along with the potential for future FOAS use and for other SE programmes.

1. Introduction

The Smart Procurement Initiative (SPI) launched as part of the UK Strategic Defence Review in 1998 has revolutionised the UK MOD procurement process. The primary objective of Smart Procurement is to enhance defence capability by acquiring and supporting equipment more effectively in terms of time, cost and performance. Specifically Smart Procurement adopts a through life systems approach, improved requirements capture, trade-offs, partnerships with industry and new procurement techniques such as incremental acquisition.

This process is currently being applied by a number of Integrated Project Teams (IPTs). One of these is the UK Future Offensive Air System (FOAS) IPT within the UK MOD Defence Procurement Agency (DPA).

FOAS is aimed at fulfilling the need for an offensive air capability for entry into service in around twenty year's time. This capability may require a 'force mix solution' involving a combination of air vehicles, including manned aircraft, Uninhabited Combat Air Vehicle (UCAV), Air Launched Uninhabited Air Vehicle (ALUAV) and Conventionally-armed Air Launched Cruise Missile (CALCM) - all operating within the digitised battle-space of the 21st century.

One facet of Smart Procurement is the adoption of Synthetic Environment (SE) Based Acquisition

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(SeBA) which provides a framework for the use of Synthetic Environments within Projects.

In the UK context a Synthetic Environment (SE) is defined as "linking a combination of models, simulations, people and real equipment into a common representation of the world" [1].

As part of the FOAS programme, a SE project is being conducted, aimed at delivering a FOAS Synthetic Environment (FOAS-SE) Demonstration. This will initially form part of the Concept Study Phase of the FOAS programme and any results obtained will be used to supplement the more traditional approach to concept studies, which are based on high level Operational Analysis (OA) techniques.

The FOAS-SE Demonstration Project is a collaborative, jointly funded project involving MOD/DERA (Defence Evaluation & Research Agency), MOD/DPA (Defence Procurement Agency), MOD/Deep Strike, MOD/SECO (Synthetic Environments Co-ordination Office) and UK Industry. The industry partners include Aerosystems International (AeI), Alenia Marconi Systems (AMS), BAE SYSTEMS Warton, BAE SYSTEMS Avionics, British Telecom (BT) Defence, CORDA, Matra BAe Dynamics UK Ltd (MBD) and Thomson Training & Simulation (TT&S).

Phase 1 of this Demonstration is split into two Stages. Stage 1 captured the User and System Requirements and was followed by a top-level design of the SE capability - this project stage concluded with a formal Design Review on 21st December 1999. Stage 2 includes the development of the SE capability and a subsequent study of force mixes and concepts of operation (CONOPS) based on using the SE. During the Stage 2 development an Initial Operating Capability (IOC) was successfully delivered to the MOD and Industry Customers on 31st March 2000. As part of Stage 2 the project plan called for the demonstration to be delivered through three 'Exercises' to be run between June and October 2000.

The FOAS customers are from MOD/Deep Strike and the DPA. Within UK Industry, the customers are potential future system component suppliers to the FOAS programme and the UK simulation/SE community.

Knowledge and experience gained from previous distributed simulation research projects carried out within the UK has provided a valuable source of information towards the development of the FOAS-SE. Examples of these earlier projects include "STOW-97" [2] and "FlasHLAmp" [3,4]. In particular, Project "FlasHLAmp", was initiated in 1996 to provide MOD, DERA and Industry with an early understanding of the use, development and application of the US High Level Architecture (HLA) for event driven and human-in-the-loop (HumITL), real-time simulations. The key FlasHLAmp objectives included:

⇒ to transfer HLA technology and knowledge into the simulation and modelling communities within the UK defence industry;

⇒ to identify, and where necessary evolve those concepts, techniques and tools necessary to allow UK simulation applications to effectively exploit the HLA;

⇒ to demonstrate the applicability of tools, techniques and guidelines using an agreed prototype federation of HLA models and simulations;

⇒ to provide draft guidelines for specifying interoperability requirements when procuring models and simulations;

⇒ to investigate the integration of legacy (e.g. DIS-like) simulations interoperating within an HLA framework.

Building from this experience, this paper aims to present the activities and lessons learned within the FOAS-SE Demonstration Project; from the initial requirement [5] through to the design, development and operation.

2. Requirements

2.1 User Requirements

The fundamental FOAS requirement is for an offensive air system effectively replacing the capability currently provided by Tornado GR4 by approximately 2020. A more detailed discussion of specific roles and functions is provided at [5], which also describes the original aims, objectives and requirements on the FOAS-SE in support of the overall FOAS programme. At that time, the procurement process was undergoing a change as a result of the Strategic Defence Review to implement the Smart Procurement Initiative. This led to a revision of the FOAS programme based on the new process.

However, this did not change the fundamental assumption within FOAS that exploitation of SE would provide improved flexibility in the FOAS system design to allow decisions and design freezes to be made closer to the service date than previously possible.

The aim in FOAS remains to head towards an animated Weapon Systems Specification that provides simulations of the required system in an unambiguous form.

The initial aim during the Concept phase, at the time called the Feasibility Study stage, was to conduct a series of demonstrations building on existing UK SE activities. The aim of the demonstrations being to provide:

- data to assist with the development and validation of the FOAS force mix and Concept of Operations;
- further confidence in the use of SE in the acquisition process;
- a forum for SE capability development.

In the short term, it was intended to have the demonstrations show how such an early investment in SE can improve the quality of the overall requirements and level of common understanding across the supply chain. To focus the demonstration, an experimental question was derived:

“What are the effects on tactics and system effectiveness of changing the roles (and capabilities) of Uninhabited Air Vehicles within a FOAS Force Mix?” [5]

To answer this, a mixture of man-in-the-loop virtual and purely constructive mission simulations were planned. Findings would feed in to the FOAS submission for Initial Gate approval.

The FOAS-SE is primarily required to operate within a core facility co-located on a single site, to a classified level. An additional requirement is to demonstrate a secure connection to at least one remote site, since any long-term development of this SE capability will have to provide for a geographically dispersed capability. Connection to one or more remote sites will be used to demonstrate risk reduction of using UK high-speed encryption devices within a real-time SE application involving multiple entities, i.e. requiring high bandwidth and low latency.

The FOAS-SE Demonstration is required to be capable of simulating a co-ordinated coalition air-attack, one element of which will be FOAS. During the exercise study the scenario is executed several times for each of the FOAS force mixes to allow refinement of concepts of operation and tactics. The SE is also required to support both 'Monte-Carlo' type statistical analysis of varying fundamental parameters within the study scenario, in addition to supporting the execution of the study scenarios in real-time to enable human-in-the-loop assessments of particular cases.

2.2 System Requirements

The FOAS-SE consists of a core set of hardware and software systems co-located on a single site and connected together using a Local Area Network (LAN) infrastructure. This is known as the FOAS-SE Primary Site (figure 2-1).

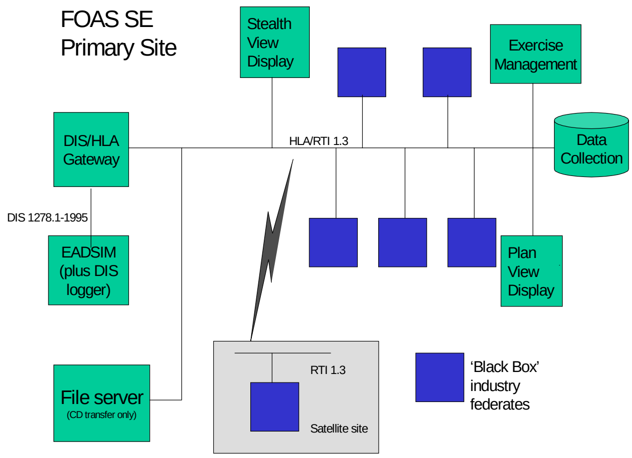

Figure 2-1: FOAS-SE Primary Site Infrastructure

One of the design goals in the development of the FOAS-SE Demonstration was to provide a high degree of flexibility in the process by which candidate models and simulation applications could be integrated, tested and executed within the SE. Furthermore components of the SE are required to execute in different time domains, i.e. real-time and faster than real-time. In order to meet these requirements the development of the FOAS-SE was based around the HLA and a number of core systems (table 2-1).

FOAS-SE CORE SYSTEMS
EADSIM (Core Battle Model)
DIS Logger
DIS/HLA Gateway
Federation Verification Tool (FVT)
Federation Management Tool - "Director's Chair"
HLA based 2D Plan View Display (PVD)
HLA based 3D Stealth Viewer
HLA based data collection/replay capability
File Server to maintain configuration control and provide a single point of access for importing software into the SE.
Backup File Server

Table 2-1: FOAS-SE Primary Site Support Tools

The LAN transport used to connect components of the SE is implemented to support network traffic at a sustained bandwidth, which is suitable for interactions between real-time simulation systems. In addition to the LAN a secure Wide Area Network (WAN) infrastructure has been configured to provide communications to two remote (i.e. satellite) sites. Each of the satellite sites is set-up to execute one or more simulation model applications relevant to the FOAS-SE Demonstration.

The FOAS-SE Demonstration utilised existing public network providers. The FOAS-SE WAN is required to support the transmission of classified data using UK accredited encryption devices. This involves the implementation of ‘End-to-End Encryption’ involving the insertion of suitable serial bit-stream encryption / decryption units between the Primary Site LAN and the public WAN.

In addition to data, other information is required to be transmitted over the secure WAN infrastructure; this includes both audio and video information.

Commercial security issues are addressed by ‘black box’ integration and testing.

The System Design for the FOAS-SE is based on the integration of a traditional OA modelling tool, i.e. EADSIM (Extended Air Defence Simulation). Referred to generically within the project as the Core Battle Model (CBM) this is used to support pre-demonstration battle modeling activities with the objective of scoping the detailed requirements for SE implementation.

The CBM is required to be populated with Computer Generated Forces (CGFs), i.e. constructive simulation entities.

The CBM is also required to support an interface to HumITL (virtual) simulation devices, in addition to other constructive modeling systems, operating in a real-time domain.

The FOAS-SE Demonstration requires there to be a single Synthetic Natural Environment (SNE) database based on digital data sources for an appropriate area of terrain. The single, common SNE is required to consist of a single source database from which all simulation system domains (e.g. visual, CGF, sensor), derive their run-time representations.

The SNE database is represented and distributed in recognised database formats including derived DTED (Digital Terrain Elevation Data) Level 1 and Multigen OpenFlight.

A large 'fly over' area, defined as the Base Level terrain database, is required to represent the geographical contours and cultural features; area features such as forests and towns are elevated; no point features are included. Medium Level terrain areas are required for the UAV, UCAV and CALCM flights.

Generic 3-D visual models are geo-typical rather than geo-specific, i.e. typical of the locality rather than representing specific geographical features.

The level of 3D modelling for urban areas is also geo-typical rather than geo-specific. Urban areas are replicated to reduce development costs and time-scales. Therefore, a single model, which represents a small town, can be used for all small towns. Similarly, for large towns, villages and cities.

The SNE is required to support weather effects (e.g. cloud layers) across all relevant simulation domains within the SE; these effects are static and uniform.

The FOAS-SE Demonstration is required to support data collection, data replay and data analysis, based on the use of commercially available software tools where possible and tailored to provide results in the required format.

All data captured is time-stamped to ensure that a correlation of events can be retrieved during later analysis work. This includes, but is not limited to the following:

⇒ digital recording of simulation entity state information, including platform position, velocity, appearance and damage state, munitions fire and detonation events, communications, RF emitters, etc;

⇒ audio and video recordings of operator actions and other communications not otherwise recorded digitally;

⇒ other data gathering (whether paper based or computer aided), including participant questionnaires and other observations.

Facilities are provided to the analysis team to allow read back and correlation of the data from the above recordings.

The data is recorded and stored on media suitable for meeting long term storage requirements, relevant to the life cycle of the FOAS Programme.

3. Design & Implementation

The main design objectives for this stage of the SE Demonstration were to provide a stable, flexible and comprehensive Federation framework in which many different types of simulation models could be added. This allows flexibility in setting overall mission objectives and flexibility in the type of operational analysis to be performed from the results of any given Federation execution.

To meet this objective a number of key components are needed. Firstly, a common set of Operator Stations is required which support the appropriate functionality for each platform entity, re-configurable by the use of simple text files and databases. The use of a generic Operator Station provides a common approach to the Human Machine Interface development and reduces the learning curve for Operators. Common tactical maps, icons and controls are available on all of the displays.

Secondly, a number of services which are required by many Federate applications are provided by a few simulation 'servers'. This includes a Weapons Modelling Federate (WMF), a Radio Communications Model, a set of common Sensor Models and a Mission Planning Station.

The WMF handles all the blue force 'simple' munitions that are not part of the main FOAS concepts and calculates the impact time and position of those weapons after release.

The Radio Model is implemented within the STAGE modelling tool and uses both a satellite and a line of site (LOS) model. The LOS model incorporates the simulation of High Altitude Long Endurance (HALE) UAVs. This provides a facility to handle terrain-screening effects, propagation delays and attrition factors affecting the overall mission control and outcome.

An important aspect of the operational analysis is the use of verified sensor data sets used by specific entity platforms. The sensor models are also implemented within STAGE and a common interface for their use has been established.

Key to executing the Federation missions was the mission planning and the dissemination of the routes to all the blue platforms. A single Mission Planning Station is provided that imports routes generated by the Core Battle Model, i.e. EADSIM. The mission routes are then transmitted to all the appropriate blue platforms for their execution at the desired time. Key to the analysis of the FOAS concepts is an understanding of the interactions between all of the different platform types. The Mission Planning Station enabled experimentation with different force mixes and their mission objectives.

The third key component is the FOAS platforms that model the FOAS concepts. These simulations are mainly derived from legacy research simulations, adapted and enhanced to support the FOAS-SE Demonstration.

The Federate modelling and simulation applications are supplied by the UK Industry partners, based on the output of the design phase which was co-ordinated by DERA. During the Federation development process a 'top down' design approach was adopted, using the Real-time Platform Reference Federation Object Model (RPR-FOM) as a baseline for development. The RPR-FOM has since been extended to incorporate many FOAS specific communication and data logging interactions (see below).

The baseline FOM template includes a definition of the format and semantics of data messages that are exchanged between simulation applications and simulation management (sometimes referred to as federation management).

The data messages provide information concerning simulated entity states, the type of entity interactions that take place in a distributed simulation exercise, and data for the management and control of the exercise.

Primary consideration was given to those simulations and models that could demonstrate HLA compliance and could support the RPR-FOM. Legacy DIS (Distributed Interactive Simulation) simulation models were only considered if there were clear plans within the time-scales of the FOAS-SE Demonstration project to implement an upgrade to the HLA.

Legacy DIS simulations were required to comply to IEEE Standard 1278.1-1995. Specifically this included the following set of protocols / messages:

⇒ DIS Entity State PDU (IEEE 1278.1-1995);
⇒ DIS Fire PDU (IEEE 1278.1-1995);
⇒ DIS Detonate PDU (IEEE 1278.1-1995);
⇒ DIS Emissions PDUs (IEEE 1278.1-1995);
⇒ DIS Simulation Management (SIMAN) PDUs (IEEE 1278.1-1995).

The use of the RPR-FOM allowed many HLA middleware layers that were available within UK Industry to be re-used, including 'SEAPI' from MBD and 'SimConnect' from AMS. Furthermore, the RPR-FOM supported all the main platform interactions that were required. Figure 3-1 lists the

Federate application types (excluding support tools) used in the FOAS-SE:

RED FORCES
Core Battle Model (EADSIM)
BLUE FORCES
Mission Planning Station
Operator/Pilot Stations
Platform Dynamics Models
Sensor Viewers
Sensor Models (via STAGE)
Radio Model (via STAGE)
Weapons Model Federate (WMF)
Recognised Air Picture Display (RAP)

Table 3-1: FOAS-SE Federate Types

One area that needed enhancements however, was communications. To allow for future capability and ease of use a set of three communications interactions were added which evolved the baseline RPR-FOM into the FOAS-SE-FOM. This allowed communications to be directed via the Radio Model and bypassed when modelling subsystem to subsystem communications (e.g. platform ←→ sensor). A simple text based messaging system was developed and a set of commands and status information was encoded to allow maximum flexibility. A 'comment' interaction has also been added to allow Federate applications to log key mission events that were unavailable as part of the original RPR-FOM. Another addition which has been included as part of the FOAS-SE-FOM is a set of Observer Interactions used for the remote control of a 3D Stealth Viewer and for the control of IR and Visual sensor displays.

In the context of developing the FOAS-SE-FOM an important lesson learned by the FOAS-SE Design Team is the need to capture all discussions and agreed decisions relevant to developing the FOM. Specifically the Design Team needs to:

⇒ review the FOM, focussing on potential ambiguity, which are complemented by Notes;
⇒ maintain a FOM Design Document which MUST be updated to reflect any relevant verbal discussions/decisions;
⇒ issue the FOM Design Document to all suppliers of Federate applications when any changes are made.

3.1 FOAS-SE Integration & Testing

The networking infrastructure for the FOAS SE Demonstration has been achieved by providing an Internet Protocol (IP) based Local Area Network (LAN) at the Primary Site, and a transparent LAN to LAN connectivity to remote (satellite) site(s). All current simulation interoperability standards are IP based, including DIS (IEEE 1278.1-1995) and HLA Standard, IEEE 1516.

Due to time and budgetary constraints, particularly related to the requirements for high bandwidth long haul secure network connections, the site-to-site WAN connectivity has been implemented using existing public services based on MegaStream circuits. This is a switched telecommunications service, which is readily available in the UK at reasonable start up and rental costs, with a data bandwidth of up to 2 Megabits/second (equivalent to Primary Rate ISDN) - peak utilisation is estimated at approximately 1.2 Megabits/second.

Simulation Management using the SIMAN start/resume and stop/pause interactions has been used through a central Federation Management Tool called the 'Directors Chair'. This provides a basic level of control although some manual start-up process is required since the Federation includes a DIS application through a DIS/HLA Gateway.

HLA Time Management Services have not been used within the FOAS-SE because the federation is currently executed in real-time and is not constrained by events in time. During real-time execution the federate platforms are synchronised to wallclock time using Network Time Protocol (NTP).

The integration of many complex simulations and tools has been achieved through a steady evolution of the Federation rather than a 'big bang' approach. Starting from the Initial Operating Capability (IOC) Federation, individual Federate applications have been integrated in a phased manner.

Each Federate is required to be tested in a local networked environment before integration. This reduces many integration problems and allows a stable Federation to evolve.

Federate simulation models are accepted for integration into the FOAS-SE following 'black box' testing. The testing of simulation models includes consistency checking to ensure that models are consistent within themselves as well as being mutually consistent with each other. This is achieved via SOM/FOM consistency checks.

The FOAS-SE Test & Verification Strategy document outlines the test and verification processes to be carried out in more detail, including the testing to be performed at the Federation level (see figure 3-1 for the FOAS-SE document roadmap).

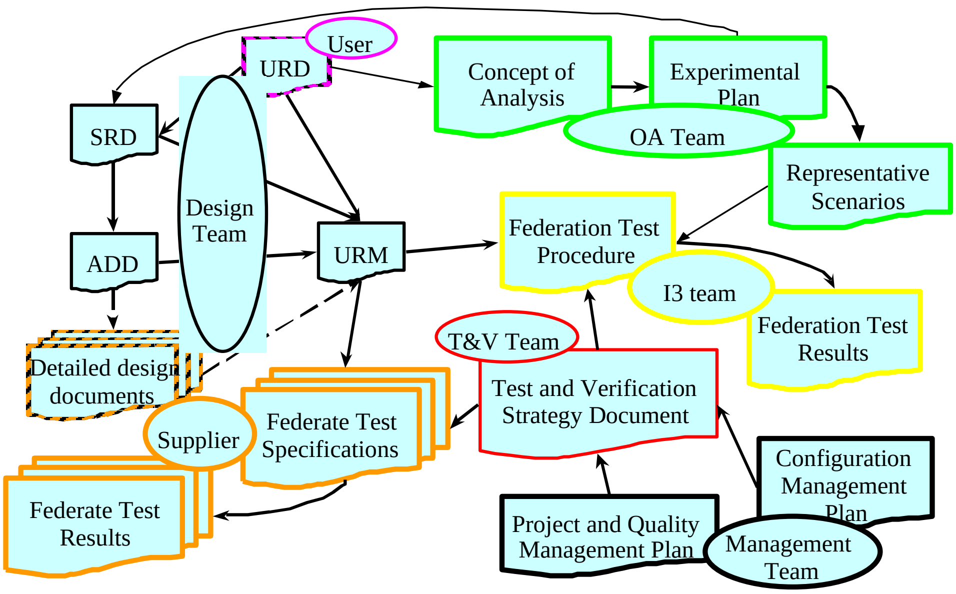

Figure 3-1: FOAS-SE Document Roadmap

3.2 COTS Software Tools: Tool Acquisition

The Commercial-off-the-Shelf (COTS) tools used within the FOAS-SE Demonstration Facility were obtained from the Defence Modelling and Simulation Office (DMSO) via the Software Distribution Centre (SDC) and from the Institute for Simulation and Training (IST) sponsored by Simulation, Training and Instrumentation Command (STRICOM) via a distribution agreement.

The Run-time Infrastructure (RTI) 1.3v6, the Federation Verification Tool (FVT) 1.3v3, the Java Bindings Version 1 for RTI 1.3, the Data Collection Tool (DCT) 1.3v3 and the Object Model Development Tool (OMDT) 1.3v4 were obtained from DMSO and the DIS/HLA Gateway v3.3 was obtained from IST.

The COTS tools generally worked well, although a number of problems had to be resolved, requiring assistance from the originators. A comprehensive description of the use and issues involved in applying these COTS tools is described at [7].

4. Exercise Management

4.1 Structure

The FOAS-SE programme employed two approaches to modelling. Initial pre-demonstration battle modelling was conducted within a closed constructive simulation to provide early guidance on the missions to be investigated. The findings from this modelling were used to steer the definition of the larger series of human-in-the-loop SE exercises. This paper concentrates on the more complex, real time, human-in-the-loop SE.

The FOAS-SE programme comprises four main teams. The Management Team provides overall co-ordination and direction to the programme. The Design Team is responsible for the creation and delivery of the software and hardware components of the FOAS-SE. The Analysis Team designs the experiments to be conducted by the FOAS-SE and the Exercise Team schedules and operates the SE during the exercises.

The Exercise Team was created a few months prior to the first FOAS-SE exercise in June 2000. Broadly, the remit of the Exercise Team is to ensure the FOAS-SE exercises are successfully completed in accordance with the Concept of Analysis and Experimental Plan as defined by the Analysis Team, within the functionality implemented by the Design Team.

A simple, but effective, process (shown in figure 4-1) was instigated to allow continued development of the FOAS-SE, whilst ensuring the integrity of the system during the exercise runs.

Activity	***Responsibility***
Development / Mission details	*Design Team / Analysis Team*
System Testing	*Design Team*
Integration	*Design Team*
Full Systems Testing	*Design Team*
Rehearsals/mission interaction testing	*Exercise Team*
Operational exercise	*Exercise Team*
Exercise review	*Analysis, Design & Exercise Teams*

Figure 4-1: Basic FOAS-SE process

Development of the SE federate systems has been an ongoing activity throughout the exercises. Typically, development takes place away from the core FOAS-SE facility. When a component is ready for insertion to the SE, a remote test of the amended federate system is conducted using a test harness environment. If this is successful, then the federate is integrated within the FOAS-SE and a full systems test conducted within the real environment of the FOAS-SE, rather than the test harness.

At an agreed date before the next exercise, approximately one week, a stable FOAS-SE baseline system is formally handed over to the Exercise Team. This is then used for rehearsing the operational exercise procedures and testing all conceivable mission interactions.

Based on the results of the rehearsals and mission interaction testing, the exercise schedule is revised if necessary. The operational exercise can then begin using a stable SE running known missions. Post-exercise run, a review session is held with all teams to identify lessons learnt and prioritise activities for the next phase.

All these activities are designed to minimise risk during the operational run in order to maximise the number of valid mission runs achieved to optimise benefit from the exercise. This process has been very successful. Despite a number of developmental difficulties, a stable baseline has always been delivered. To date, there have not been any non-recoverable systems failures observed under exercise conditions.

4.2 FOAS-SE Configuration

The FOAS SE is comprised of a number of computer models, simulation systems, operators, observers, military players and the processes for operating all of these components and roles. The main site for the FOAS-SE facility is DERA Farnborough. Two remote sites have been connected via a secure Wide Area Network (WAN), allowing up to three sites to participate in the exercises: DERA Farnborough, BAE SYSTEMS Warton and MBD Stevenage.

The first FOAS-SE exercise was run purely from the DERA Farnborough site and figure 4-2 shows the layout of the SE.

The FOAS SE is a High Level Architecture (HLA) compliant federation, consisting of a number of federate systems interoperating through an agreed interface – the Run Time Infrastructure (RTI). EADSIM (Extended Air Defence Simulation) provides the representation of all enemy forces and targets. This is a constructive Computer Generated Force simulation system with detailed models of force behaviours, which is largely prescriptive, with limited reactive capabilities. EADSIM is not HLA-compliant and so the HLA/DIS Gateway software provides the interfacing mechanism between the FOAS SE HLA federation and the EADSIM DIS network. The DIS Data Logger is the only other system on the DIS network and is used to capture a record of DIS network activity for the purposes of replay.

The main file server for the FOAS SE also runs the RTI software. The RTI, along with the Federation Verification Tool (FVT), is used to create the federation and monitor the status of the federates as they join the federation. Once all federates have joined, the FVT is terminated due to its heavy processor load on the server.

A 2D Map Display federate provides a ground truth picture of all forces and targets within the SE, as well as information on these entities. A 3D Display (called a stealth display because it is passive within the federation, incurring minimal cost in terms of network traffic) provides a 3-dimensional view of the environment. The Data Collection Tool (DCT) records a log of all federation network activity to help support analysis of events after a mission run.

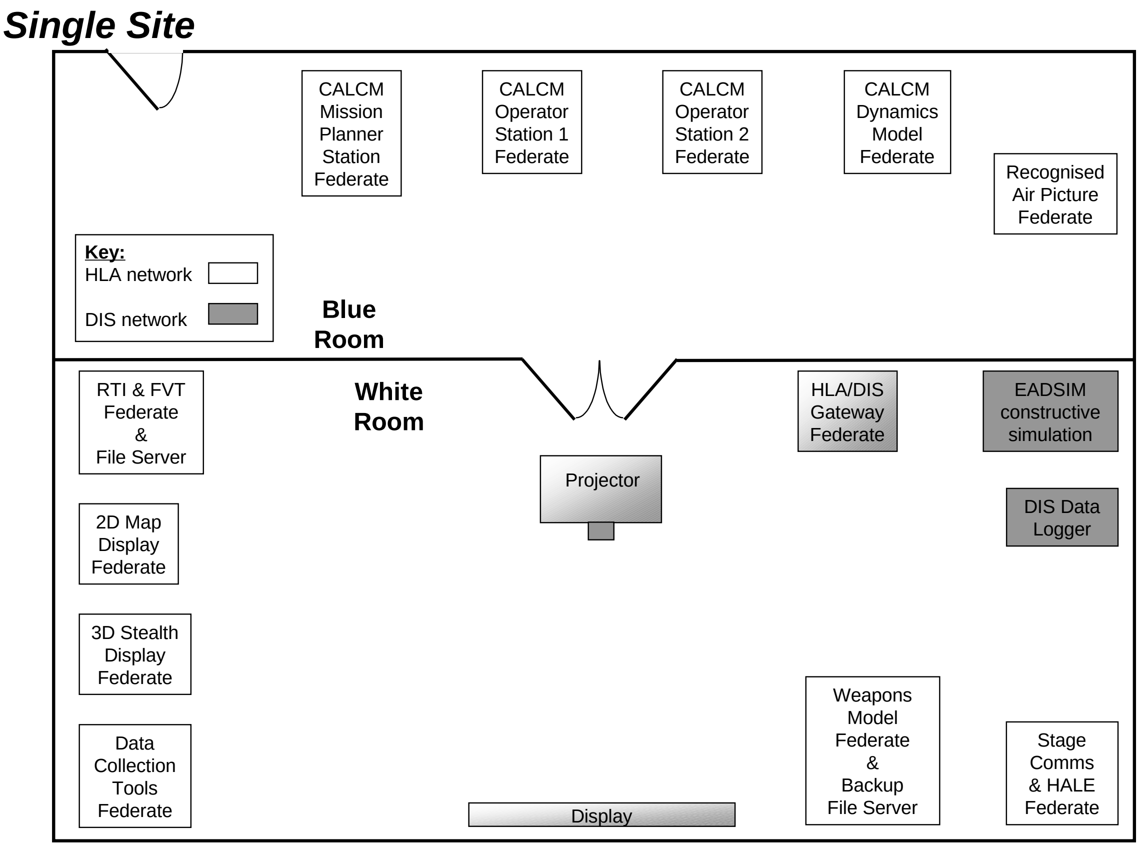

Figure 4-2: Diagram of FOAS SE for Exercise 1

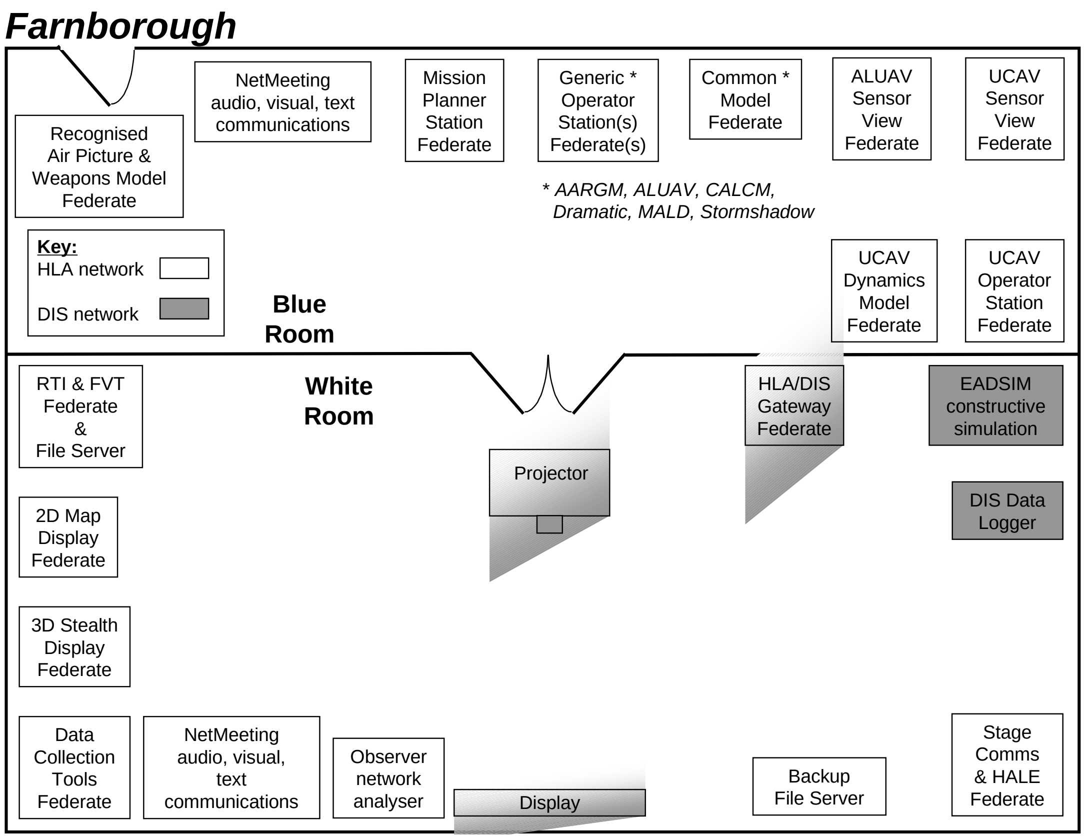

Figure 4-3: Diagram of Exercise 2 layout at DERA Farnbororough

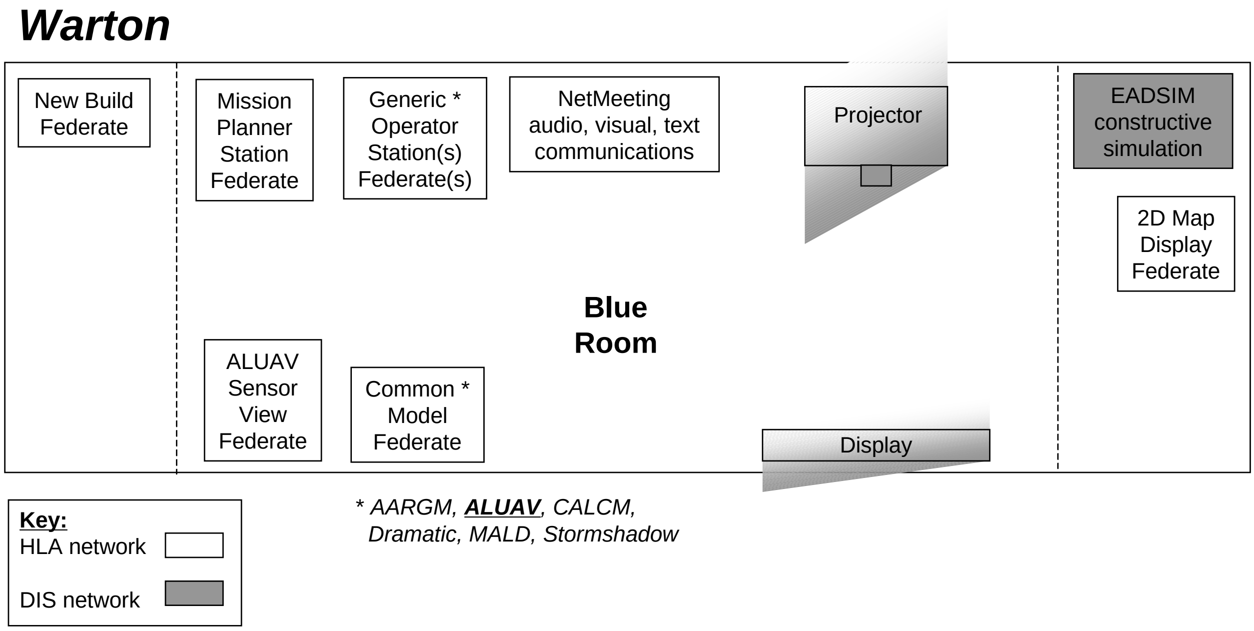

Figure 4-4: Diagram of Exercise 2 layout at BAE SYSTEMS Warton

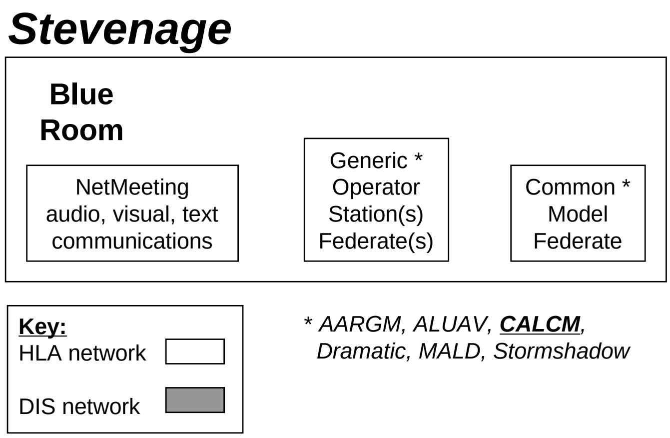

Figure 4-5: Diagram of Exercise 2 layout at MBD Stevenage

The Weapons Model Federate (WMF) determines the effects of certain Blue weapons within the SE. The Stage federate is used to provide the communications between Blue forces under control from operator stations. This provided representations of both satellite and High Altitude Long Endurance (HALE) platforms. Stage also provides the sensor information that stimulates the operator sensor views.

A backup file server is also present. This maintains a copy of data files from the main server, as well as the ability to provide the RTI and FVT tools should the main server become unavailable.

All the above systems reside in the 'white' room. This is designated 'white' as it contains both exercise management tools, providing a ground truth or white picture, and is the centre of operations for the Red commander. A projection facility is also available to provide pictures from a number of the federate computer screens in the white room. This display assists with the management of the mission run and is also used during debriefing to a larger audience.

The 'Blue' room houses information that would only normally be available to Blue players. For exercise 1, this consisted of federates providing a mission planning station for defining routes and re-routing of the Conventional Air Launched Cruise Missiles (CALCMs), a CALCM operator station to issue commands to the CALCMs and the dynamics model for the CALCMs. The only other system in the Blue room is the Recognised Air Picture (RAP), which gives a time-delayed picture of the scenario, representative of the type of information that would be derived by the Blue Intelligence cell.

Exercise 2 built on the facility used during Exercise 1. However, there were a number of significant differences between the two exercises. The main distinctions being the increased number of federate systems used and the distributed nature of Exercise 2.

During the exercise, three geographically separated sites comprised the SE. The main support site, hosting the white room functions, remained at DERA Farnborough. However, depending on the particular missions run, the Blue room functions were conducted across a combination of one or more of the SE sites at DERA Farnborough, BAE SYSTEMS Warton and MBD Stevenage. These sites are linked through 2Mbit Megastream connections, using MOD accredited encryption devices at each site.

Figure 4-3 shows the Exercise 2 layout for the SE at DERA Farnborough, which built on the original Exercise 1 configuration.

In addition to the Exercise 1 federates, the following systems were introduced for Exercise 2.

The mission planning, operator and common model federates employed for Exercise 1 were originally used solely to plan CALCM missions. These federates were used during Exercise 2 as generic systems for a range of Blue assets. The mission planner, operator and common model federates were used for Advanced Anti-Radiation Guided Missiles (AARGM), Air Launched Uninhabited Air Vehicles (ALUAV), CALCMs, Dramatic munitions, Mobile Air Launched Decoys (MALD) and Stormshadow missiles. In addition, the mission planning station was used to create and send routes to the New Build 1 aircraft and the Uninhabited Combat Air Vehicles (UCAV).

The UCAV federates provide an operator station, model and sensor view for representing and controlling up to four UCAVs, using routes received from the generic mission planning station. In a similar fashion, the ALUAV federates utilise the generic operator station and common model, with an ALUAV sensor viewer, to provide control of the ALUAV craft.

As well as the HLA federates, two new (non-HLA) systems were introduced. The Observer network analyser package was used to monitor the network status during SE use. Microsoft NetMeeting was also used, in conjunction with the Creative Labs Web Cam II camera and microphone, to provide electronic conferencing facilities between the sites over the secure network.

Figure 4-4 shows the SE layout at BAE SYSTEMS Warton. This site was used for the New Build 1 missions, using the New Build 1 manned simulator and automated aircraft, which often called for ALUAVs to be flown in conjunction with the New Build 1 aircraft.

The third site was based at MBD Stevenage and was used to assist with the running of CALCMs when required. This is illustrated in figure 4-5. However, both the Warton and Stevenage sites were capable of running varied configurations using the federate systems available at each site. The range of systems the common models were able to support is listed in figures 4-4 & 4-5, with the primary federate employed during Exercise 2 highlighted in bold and underlined.

By the time of the second exercise, the FOAS-SE facility comprised three separate sites, providing 24 discrete HLA-compliant federate systems. During the second exercise, some 17 missions were conducted over 6 working days. The largest mission scenario consisted of 18 federates running simultaneously, modelling over 400 entities, across three sites. Manning requirements for the largest mission run was approximately ten personnel, covering aircrew, operator, observer and exercise support functions. No unrecoverable system failures occurred during either of the exercises.

4.3 Running the exercise

A set of practical procedures was put in place in order to operate the FOAS SE during the exercise runs. The aim was to provide a formal structure and chain of command for the running of the exercise missions. This section gives an overview of the processes used to manage the SE.

A structure around each mission run was created. This consisted of pre-mission set-up, briefing, initialisation, operation, closedown and debriefing stages. Initially it was possible to achieve two mission runs per day. However, once the exercise personnel were familiar with the procedures, and depending on the length of the actual mission run (as the missions run in real time), it was possible to adapt the timings to readily achieve three mission runs per day.

The immediate chain of command for the exercise revolved around three basic roles. The Exercise Director was ultimately responsible for the operation of the SE and this lead function was supported by two further roles, namely the Analysis and Design Team leaders. Before initiating a mission run, or making key decisions on the nature of a mission or technical SE issues, the Exercise Director would seek confirmation from the Analysis and Design Team leaders as appropriate.

The pre-mission set-up stage required the Exercise Support Team to provide a basic check that the SE was ready to be used. This involved powering up (or rebooting) all relevant equipment and ensuring the computers were safely logged in under the exercise accounts. A check was also made that all required personnel were present and ready.

The briefing stage was split into two sessions. The first session was in the Blue room and covered Blue mission details, the composition of the SE to be used, roles for the mission and general questions. The second session took place in the White room and excluded Blue command personnel. This session was primarily to inform the observers of overall mission details and expectations.

For distributed missions, where the Blue aircrew, operators and support staff were not all at the same site, Microsoft NetMeeting was used for the briefings. A combination of microphone/speaker and text-based NetChat communications were used. This worked well, with the added bonus of providing a searchable log of communications between the sites were NetChat was used, and this was maintained throughout the briefing and operational mission run. However, the nature of NetChat meant that communications were brief, which allowed for some loss of clarity during certain mission explanations.

While the white briefing session was occurring, the SE initialisation process commenced. This involved an orderly run up sequence to bring all the component systems into the SE. Due to the developmental nature of some of the software and ongoing testing of some of the SE systems, it was necessary to impose a rigorous, but known, procedure to bring the SE on-line in order to reduce any opportunity for unwanted effects. This resulted in an extremely stable SE.

A manual start initiated the exercise and operational use of the SE. 0000hrs was defined from the simulation clock in the EADSIM constructive simulation system. This occurred before the SE was fully operational (as EADSIM was not necessarily the last component to enter the SE as part of the run-up procedures). Once all SE systems were on-line, the instruction to begin the mission run was made by the Exercise Director, authorising the Blue Commander to release the Blue forces.

During the mission run, all personnel had a series of questionnaire forms available for capturing noteworthy events, from mission engagements to comments on the SE functionality.

Once an ‘end game’ situation had been reached, and agreed between the Exercise Director, Analysis and Design Team leaders, the exercise was halted and SE closedown procedures instigated. This involved a formal removal of systems from the SE, along with procedures for copying captured data from the systems to the main file server. From here, details for each mission were logged and recorded on CD as well as the daily backup tapes. This information was then made available to the Analysis Team.

Debriefing was the final stage of the exercise procedures. For distributed missions, the debriefing took place at the site with the Blue aircrew. During debriefing, EADSIM was used to replay the mission through the projection system for all exercise personnel. Verbal comments on the mission were elicited and formally captured through the questionnaires. Based on the debriefing session, changes may result in the order of subsequent missions.

The end of the debriefing session marked the termination of the procedures for the SE mission, pending any remaining data to be copied to the server as part of the SE closedown procedures. The SE was then available for the next mission.

4.4 Results

The detailed analysis of the FOAS-SE demonstration is not due to take place until after the third exercise in October 2000, when all data has been collected. At the time of writing, only two of the three planned exercises have been conducted. Preliminary analysis has taken place between each exercise, producing interim reports, and indeed it was possible to do some early analysis during each exercise. However, the remit of this paper is not to cover the analysis findings, but to describe how the SE was employed to support the analysis process.

Before each exercise, the Analysis Team planned out a series of mission experiments to conduct during the exercise. As a result of early analysis findings during the exercise and feedback from the debriefing sessions, an improved understanding of the issues involved was gained. This led to the ability to better define the types of mission runs required to support the analysis process.

Mission planning therefore became an evolving process, with many of the mission runs initially planned for each exercise adapting as a result of early findings. This allowed the runs to focus on the emerging key issues. Despite generally fitting in three mission runs per day, it was usually possible to modify the subsequent mission runs on a mission-by-mission basis without too much difficulty. Such was the flexibility of the FOAS-SE.

5. Lessons Learnt

The FOAS-SE is a complex system comprising varied components, many of which remain under development. As with the production of any such system, a number of problems had to be overcome to deliver a working baseline for each exercise.

An evolutionary method to building the FOAS-SE was adopted, rather than a 'big bang' approach. This helps to reduce a number of integration problems by building on a stable, known environment. One system at a time is added to the SE and tested. If necessary, the new federate or other components within the original federation, may be adapted in order to achieve a new, stable system.

Prior to integration testing with the FOAS-SE, federate systems were required to have undergone local checks using a test harness to provide a representation of the FOAS-SE environment. Having proved themselves in the local tests, new federate systems would then be tested and integrated with the latest stable FOAS-SE baseline.

Although this gradual approach to building the FOAS-SE is believed to have reduced a number of difficulties that may have occurred, several problems were still observed. The majority of technical issues centred on the stability of the connection of a federate to the FOAS-SE federation, and the ability of the federates to deliver the specified functionality within the short timescale available.

It would often be the case that a system would work as specified under local testing conditions, but not within the actual FOAS-SE environment. Resolving some of these problems could take a significant time. Part of this difficulty was due to the fact that much of the FOAS-SE was under parallel development and so the test harness could not be fully representative of the actual FOAS-SE environment; the test harness always being several evolutions behind the latest baseline.

This problem was significantly reduced however, when developments to systems were conducted at the FOAS-SE facility. This provided an environment where the actual SE could be used for local testing rather than the isolated test harness, and also developers were able to more easily communicate with other system developers to help keep abreast of changes.

The other key aspect to improving the likely success of an 'easy' integration, was the capture and communication of all technical decisions, particularly regarding FOM interface development. Procedures were in place to record such decisions and changes to the FOAS-SE and, in particular, the FOM Design Document. However, the maintenance and dissemination of this information could have been improved. Often time pressures would restrict the extent to which these procedures could be followed.

Limitations and constraints within the FOAS-SE led to the Analysis Team having to make a number of assumptions before interpreting the data gathered from the exercises. A balance had to be struck between delivering a SE that did not require too many assumptions to be made that might invalidate the results, and producing a working system within the time constraints imposed by the need to support the FOAS submission for Initial Gate approval. The main factors resulting in assumptions are discussed below.

Maintaining a complete audit trial of the data underlying many of the models used in the SE was difficult. The employment of a formal Data Manager role to take responsibility for this would have reduced the uncertainty associated with some of the data.

Limited functionality in the SE, due to both the developmental nature of some of the systems, and inherent limitations in others, resulted in a number of assumptions being made. Whatever systems are used, there will always be limitations with SE as, by their nature, SE will always be abstractions. Obtaining a reasonable balance of functionality, cost, time and prioritisation of ongoing developments reduces the assumptions that will inevitably have to be made.

The necessary involvement of the exercise aircrew in the preparation and testing of the SE resulted in a degree of 'learning the game'. Plans to apply multiple variations of the enemy threat for the third exercise should help to reduce this problem. Another approach, not possible with the existing prescripted simulation used to model enemy forces, is to provide a simulation system that allows the enemy commander to interactively change the enemy behaviour during a mission. Although this would require the isolation of the enemy command cell from the general exercise control systems.

During the distributed missions, communication between sites was limited by the audio, visual and text based systems available. The NetChat facility provides an excellent, searchable record of events, but is time consuming to use and restricts the quality and quantity of information conveyed. Virtual whiteboarding will be investigated for the third exercise to help improve the briefing process. Improved audio systems are also being employed to enhance the existing system, which provides a poor quality telecommunication facility that again restricted much needed communication between the sites.

6. Conclusions

In terms of meeting the original objectives, as specified at [5], the FOAS-SE has to date shown the following traits.

Initial Monte-Carlo simulation runs were conducted to steer the subsequent real time, human-in-the-loop exercises. To date, two main exercises have been conducted using the FOAS-SE, with the third and final run about to commence at the time of writing. These exercises have investigated some of the FOAS concepts within a co-ordinated, coalition air-attack scenario. Numerous runs have been conducted to study a range of missions.

DERA Farnborough hosts the core facility and the first FOAS-SE exercise was conducted from this location. The second and planned third exercises made use of the two remote sites at BAE SYSTEMS Warton and MBD Stevenage, demonstrating real time, secure connections.

Although detailed analysis remains to be conducted, initial findings suggest that the FOAS-SE has improved the general understanding of the FOAS concept and provides a common forum through which this concept can be further communicated and developed.

Preliminary results have already been fed in to the ongoing FOAS OA, backed up by a significant amount of data obtained from the exercise mission runs. Various force mix combinations have been exercised in order to improve understanding of different force mixes on the tactics employed and resulting mission effectiveness. Although the findings are dependent on a number of assumptions.

The SE proved to be extremely robust and quick to reconfigure, enabling a flexible approach to be adopted that allowed the best use of available software and experiment time.

For potential FOAS product suppliers the FOAS-SE Demonstration offers an opportunity to gain an understanding of the FOAS User Requirements and to assess the effectiveness of their proposed solutions.

For the UK simulation/SE community the demonstration offers an opportunity to gain early visibility of and participation in the expected longer-term implementation of SEs on the FOAS programme.

The study has also provided a foundation from which FOAS-SE activities can expand by generating data to support future SE investment cases and giving UK Industry an early involvement in the application of SEs to the FOAS Programme. Indeed, it is already planned to use the FOAS-SE facility to support Industry in other studies shortly after the third FOAS-SE exercise.

In the longer term, SEs may be used to increase confidence and knowledge in many areas of the FOAS programme, e.g.

⇒ requirements capture;
⇒ CONOPS development;
⇒ operational employment;
⇒ training and mission rehearsal;
⇒ test and evaluation;
⇒ acquisition;
⇒ research and development;
⇒ warfare analysis.

Traditionally, acquisition has been a linear and sequential process; the implementation of SeBA within FOAS aims to make the acquisition process more concurrent. This policy is consistent with the principles of Smart Procurement within the UK.

The core SE HLA facility now exists, with the infrastructure providing an experimental environment for exploitation by model developers, both related to FOAS and generally for the SE community.

It is believed that the FOAS-SE has successfully demonstrated the ability of SE to provide significant assistance within the acquisition process.

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The opinions expressed in this paper remain those of the authors.

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14. Abstract

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