SYNTHETIC ENVIRONMENTS: AVATARS WITH ATTITUDES

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ABSTRACT

Much progress has been made recently by national and international technical demonstration programmes on the development of Synthetic Environments. In evaluating these programmes, many commentators have pointed out how application of findings from the Human Sciences can increase the scope and effectiveness of these environments. They have called for more Human Science, but often in unfocussed and overly ambitious ways raising expectations that the Human Sciences cannot yet meet and overlooking important contributions that are ready to be made.

This overview describes key characteristics of Synthetic Environments and identifies key areas in which the Human Sciences can and should contribute. The overview identifies limitations that currently exist in applying Human Sciences to Synthetic Environments. The paper also discusses ways in which the Human Sciences should and should not be used for modelling physiological, psychological and social behaviour in Semi-Autonomous Forces; existing and still needed research in the management and control of simulation; assessment of simulation fidelity; measurement of training effectiveness; and applications in operational assessment and mission rehearsal.

A framework is provided to identify research priorities that will help satisfy the expectations of both technologists and users and that provide challenges that the Human Sciences can successfully meet. The impact and benefits of more focused and successful application of the Human Sciences to Synthetic Environments in both increasing the capabilities of Synthetic Environments and improving military operational effectiveness is indicated.

BIOGRAPHY

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[1] The views expressed here are those of the author and not necessarily those of DERA or MOD UK.

Characterising Synthetic Environments

Defining SEs

Many international forums working in Synthetic Environments (SEs) have begun by trying to agree on a definition of SE. For some, the scope of SEs includes 2-D computer worlds such as the CAD JACK™ environment[2].

SEs may also be taken to include immersive virtual environments, which have, themselves, proved difficult to define. The main point of disagreement here is whether these Virtual Reality (VR) environments must be immersive or can be non-immersive. However, no VR systems fully immerse all the senses in the environment and so all are to some degree a compromise.

In so-called 'immersive' VR the occupants of the VR environment immerse themselves through head mounted displays and haptic controls (with or without force feed back) in order to interact with as much bandwidth as possible with the virtual environment. In "non-immersive" systems the interaction with the virtual environment is via a 2-D display screen or monitor and the more conventional keyboard or joystick controls. Even here, however, it is possible for users to experience immersion, just as one can become immersed (absorbed) in the plot of a good movie.

The definitional problem for VR is particularly acute in hybrid systems in which, for instance, interaction is via a monitor viewed in stereoscopic 3-D using shuttered glasses and includes a data glove possibly with force feed back (Youngblut et al., 1996). In fact, this issue may be resolved by acknowledging *that immersion is something that is a quality of the user's experience of the interaction, rather than a property of the physical equipment*. It follows that user-based metrics should be created to produce immersion scores rather than checklists of hardware components.

Constructive models or war games now often have many features that would qualify them as SEs. The main features required are the ability to visualise the database; the provision of semi-autonomous forces (SAF); and the ability to support real time interaction.

The variety of possible simulation systems that may or may not be considered as a SE has led to a range of varying definitions. An early UK MOD definition is *"Synthesised representations of a common world which permit interactions between players"*. A UK defence focused definition is *"that combination of people, models and real equipment necessary to understand, develop and exercise defence processes"*.

What is commonly agreed is that, at its core, SEs are products of the new environment created for, and used by, simulators and simulations (models) which are connected by a Distributed Interactive Simulation (DIS) architecture and protocols. This architecture need not be the DIS or HLA standard, but should follow the same principles or philosophy behind DIS (including ADS, HLA, ALSP and DIS++); furthermore, the models/simulations need not have been designed originally to be connected together. STRICOM defines SEs as "a time and space coherent representation of an environment measured in terms of human perception and behaviour of those interacting in the environment". This definition underscores a dependency on Human Science (HS) for the successful exploitation of SEs.

With respect to the domain of training, and in accordance with the prevailing view, we take SEs to cover the following simulation types:

Live simulation – instrumented training (e.g. TES, NTC), field exercises and support to digitised warfare.

Virtual simulation – man-in-the-loop simulation (e.g. CATT/CCTT).

Constructive simulation – traditional board or computer based war games (e.g. BBGT, JANUS).

[2] JACK permits the specification of an anthropometric model of a human which can interact with an accurately modelled environment in order that workstation designs (e.g. cockpit, vehicle crewstation and command console) can be analysed.

SE APPLICATIONS

SEs benefit the defence process in five major areas[3]. These are illustrated graphically in Figure 1 and include:

Operational Analysis (OA). This comprises geopolitical analysis, strategic analysis, doctrine development, threat assessment and historical analysis.

Systems Definition. This comprises support of the equipment procurement process, evaluation & development of hardware and operational systems and Human Factors Integration (HFI – formerly known as MANPRINT).

Training. This comprises individual, team and collective skills training at all echelon levels, in all three live virtual and constructive simulation types.

Mission Rehearsal. This refers to specific pre-operational familiarisation and assessment.

Warfare. This comprises support to the warfighting process, including peace keeping & Operations Other Than War (OOTW), as well as support to aspects of the digitised battlespace.

SE Components

Independent of any particular SE application area, SEs are all characterised by a number of components. Considering the role and requirements of these components allows us to understand the differing design requirements for each application area and discuss where Human Science knowledge may be applicable. These SE components are as follows:

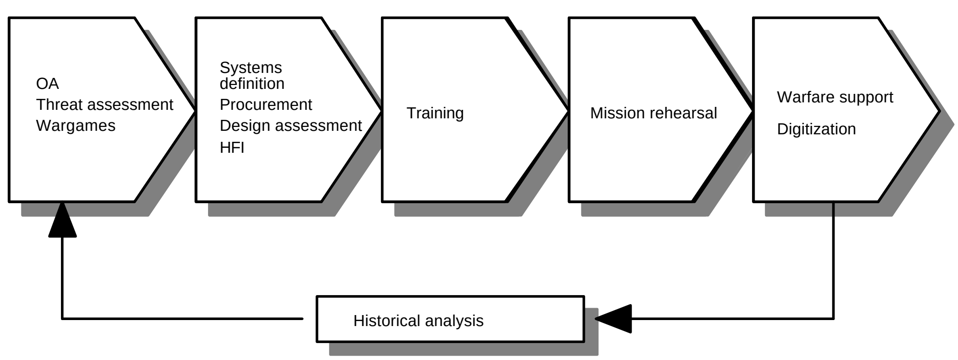
Database. SEs require a common, usually distributed, data base. This database may be realised with differing levels of realism, resolution and cultural content for different users of the SE, depending on their needs. In addition, the need for particular levels of realism (fidelity) in the database will vary for different applications and objectives of the SE.

Object models. A variety of object models need to be generated to provide visualisation of players, SAF and cultural entities. Environmental variables may be modelled as objects separate to the database.

Simulators & emulators. These provide a control and display interface to those participating in or interacting with the SE. They are visualised to others by the object models.

Semi Autonomous Forces (SAF). (Also known as Computer Generated Forces, CGF). The capability for SAF has become a uniquely defining characteristic of SE. SAF can be used to provide enemy force representations or support forces for manned simulators. They are representations of forces at all echelon

Figure 1: SE application areas in the defence process



[3] Other SEs could be constructed to address interface issues between these major applications or for minor specialist applications but we are concerned in this paper to examine the differing design requirements of these major application areas.

levels which can be controlled individually or in groups of any military size. They can be given missions and left to execute them using a limited range of rule based behaviours to respond to events, or they can be tightly controlled in near real time. Reducing the degree of control required and increasing the amount of intelligent behaviour they can exhibit are major research challenges for SE.

Performance measurement. Most SEs either have or require performance measurement systems. Performance measurement systems together with an authoring system provide the core of most After Action Review (AAR) systems that are used to provide feedback in SE-based training systems. There is a great need to improve the performance measures used in SE, particularly in the area of collective performance.

Management and control. SEs are usually large complex environments which have, in the past, been resource-intensive to set up and manage. SE management systems (SEMS) are being developed to simplify and aid this process. Above real time training in SE produces the additional burden of having to control the time base.

Verification Validation and Assessment. The wide range of applications to which SEs are being put has led to the requirement for a process to accredit SEs as fit for purpose. Accordingly, research into cost benefit analysis, training effectiveness and training transfer in SE continues.

QUALIFYING THE HUMAN SCIENCE CONTRIBUTION

Introduction

In recent years there have been many demonstrations of SEs. These have been largely technical demonstrations which have been successful in demonstrating the feasibility of constructing SEs for a range of purposes (e.g. STOW, IITSEC 92/93, BFIT, UKNCDs – see Orlansky et al, 1994). In order to make a number of points and to demonstrate the utility of SEs to number of audiences, the demonstrations have usually had more than one objective. In the main, the application areas have been a mixture of OA and training.

In the subsequent evaluation of these technical demonstrator programmes there has in most cases been either a mention that the demonstrations or similar work done in the future would be improved with improved Human Science contributions (e.g. DAFPTWP, 1998; Shiflett et al, 1995; DIS Steering Committee, 1994)

There is room for debate on what constitutes Human Sciences (see, for example, Pearn, M., 1998) and what is the best term to cover it (e.g. Human Factors, Applied Psychology etc.). Here, we will assume it is a valid perspective from which to analyse complex human-machine systems and that it is a broad knowledge domain that can contribute to our understanding of SEs.

Knowledge from the Human Sciences is applicable to many areas of SE. However, the human scientist may need reminding that SEs are a rich, new and powerful domain for the further development of human science research, while remaining cautious that care must be taken in the interpretation of behavioural data gathered in a synthetic domain.

The Human Sciences can contribute in two broad ways to improving the efficiency and effectiveness of the use of SEs in support of military operations. These are as follows:

Improving content – for example, by optimising fidelity requirements; by providing better behavioural modelling; and by specifying more effective scenario designs.

Improving method – for example, by specifying more relevant performance measurement and analysis; by designing effective feedback regimes; and by specifying efficient control and management processes.

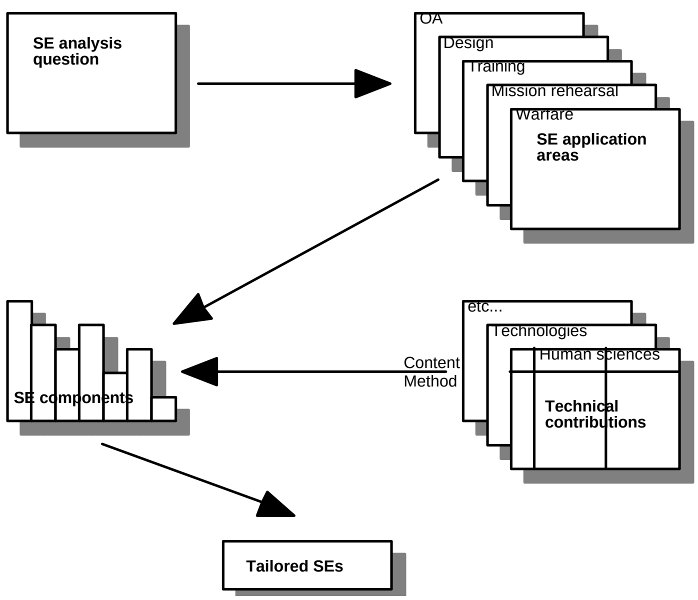
Figure 2 shows the Human Sciences contribution to tailoring synthetic environments for defence applications.

Two key topics within the broad areas of *content* and *method* deserve a more detailed examination. These are fidelity and human behaviour modelling.

Fidelity

It is still commonly thought that the prime goal of simulation is to achieve 'realism' in the simulated environment. This has made fidelity the main goal of simulation.

Figure 2. Impact of human science in SE design



However, the benefits and goal of simulation is to achieve *control* over a situation. This sort of control requires that in some cases the fidelity be reduced, eg by simplifying the environment, or by augmenting reality by providing aiding or cueing.

Fidelity has largely been treated as a simple concept, which it is not, and it has been driven by technological improvements in image generator power and display technology. This has led to an assumption that a trade off has to be made between cost and fidelity, and therefore between cost and simulator effectiveness. Many displays of military scenes are achieving visual fidelity in excess of that of the real world. The view through a smeared and muddy main battle tank sight on a dull day with various filters in place is a lot poorer than most image generators can now display.

There are many frameworks for evaluating fidelity (Hays & Singer, 1989; Rolfe & Staples, 1986; Osgood, 1949). Sub categories of fidelity that have been used are grouped into three clusters:

Physical fidelity of the simulator, including its hardware and visual systems, the fidelity with which it presents temporal, audio, visual, tactile and olfactory cues.

Operational or procedural fidelity – including how things happen, and the realism with which man, machine and environments are modelled.

Psychological fidelity, ie how simulator cues are perceived and the behaviour they elicit in the subjects, including subjects' responses to the temporal, audio, visual, tactile and olfactory cues presented.

The issue is not that there is overlap in these categories of fidelity or that the frameworks vary but that the frameworks are applied *to establish the fidelity of a simulator or simulation*.

This approach is very common and fails to recognise that *fidelity is a human-centred, perception-based issue*. Perception here is partially mind, partially brain/eye. The wider SE system including its participants, and their behavioural and social context, and the context in which the system is employed have a bearing on the underlying fidelity of the situation. By manipulating behavioural and social factors (e.g. morale, motivation, competition, peer pressure, etc.) one can alter the overall fidelity of the systems and compensate for poor device fidelity. For example, by manipulating these factors complex cognitive team tasks can be trained without negative transfer on simplified simulators that have low fidelity compared to the real world (Holding, 1991).

One is unlikely to create a military simulation, however high the fidelity, that the participants believe to be real, not the least due to ethical considerations. They will always know that they are not in a life-threatening situation. Fidelity is a value or match concept and requires people to make a value judgements of the sort: " If I wanted to, could I believe that this is a real scene image that has all (or enough) cues to enable me to carry out my tasks"? Or put another way, "Can this environment provide cues and allow me to employ the strategies and actions I need to develop or exercise, and even if the cues are not well represented can I encode them quickly and sufficiently accurately”?

The individual’s ability to block external cues (distractions) and immerse him/herself in the simulation can compensate for lower overall fidelity. The immersion and belief that children display in their games with toy guns, or just by making noises and using their fingers is a classic example of the ‘willing suspension of disbelief’ that participants will display in low fidelity simulations if they are sufficiently motivated.

Human Behaviour Modelling (Avatars With Attitudes)

This is certainly the area where there is greatest demand for the human sciences to deliver to SE. What is commonly desired is a functional model of a human that can be used to give realistic behaviour to SAF. The goal of fully understanding and therefore modelling human behaviour may seem equivalent to deriving a ‘Unified theory’ for physics; if it could be done, then the human scientist’s job would be complete. Unfortunately, and arguably unlike the physical domain, there are good reasons to believe that the reflexive, emergent nature of human behaviour makes a fully pre-determined model of behaviour an unrealistic goal.

Notwithstanding this limitation, several components of human behaviour in relation to the environment are understood and have been effectively modelled (e.g. IPME 1996). The better understood areas are the physiological stressors (thermal stress, work load, energy/water requirements, sleep depravation, etc.) though even here the interactions among them are poorly understood.

In the main, the psychological factors (personality, individual differences, morale, culture, training, team dynamics) that shape behaviour have not been modelled. However, in many military situations history indicates that it is these factors that can have the larger and dominant effect on battle outcome (Wainstein 1986).

Examples have been derived in the computer game world and applied to defence applications (Davidson, 1998) where ‘avatars’ or ‘cyberlife’ have been created with neural nets capable of learning and mediated by simple physiological models. In a simple environment these avatars interact with tasks and conditions and exhibit a type of intelligent behaviour. Repeated trials show they are capable of producing considerable variability in observed behaviour including learning after a period of time interacting with their environment, despite a common set of start conditions. This work suggests one disadvantage of detailed behavioural models applied to SE. If SAF have sufficient independent behaviour then a vast number of variables will need to be controlled in order to understand, and in training, predict their actions. Detailed audit trails will be required explaining what variables and interactions led to an observed behaviour.

In addition, if entity level behavioural models could be achieved, the required computing power needed to aggregate all the individual avatars behaviour models in real time to produce visualised gross action, would be vast. Currently the solution is to provide more realism at the command agent level; a senior level of command that is still affected by battlefield stressors and at which level it is practical to try add behavioural models.

Current levels of modelling are pragmatic and consider a number of factors (e.g. Gillis 1998). However, developers must recognise the need to model additional powerful psychological shaping factors. Developing models of behaviour for military personnel whose behaviour is based on a well documented doctrine will be easier than modelling civilian behaviour (white SAF) which will become necessary as SEs are used to research and support OOTW.

In SE training applications the introduction of realistic behaviour in SAF is driven by a perceived need for higher fidelity and is an example where reduction in the control of the simulation would be problematic. High behavioural fidelity in SAF may add too much variability for training applications by putting too many variables under trainer control and therefore increasing the Synthetic Environments Management Systems work load, or in providing unpredictable, widely varying and hard to explain SAF performance.

Currently, a Subject Matter Expert (SME) can distinguish SAF performance from real troops because SAF obey orders, keep formation, follow doctrine, and make few errors. A more refined technique based on Human Science techniques should be developed to evaluate SAF behaviour that could result in a 'Turing' test for SAF.

Framework for Examining Human Sciences Contribution to SE Applications

Table 1 maps the two broad human sciences thrusts identified earlier to the five SE application areas. The requirements for each component technology employed in constructing a SE for a particular application in the defence process varies. Some qualification of the table content is given below.

Operational Analysis. The physical fidelity of the database will depend on the level of question under examination and the resolution possible in the SE. However, constructive SEs (dominant in OA), will typically have lower resolution databases than those in virtual environments. Increased computing power will eventually provide constructive games with the resolution and entity detail that have previously been exclusively found in the virtual domain.

Usually only low model resolution is required, and these are often representations of aggregate forces (blocks or icons indicating large force structures, brigade, squadron etc.). The control of forces through emulators or Command Information Systems (CIS) may be adequate. Management and control manpower and time overheads are not yet as critical to OA as they are to other SE application areas.

Systems Definition. The systems under investigation are usually represented or exercised by simulators of high physical fidelity. It is through this procedure that SEs can show great savings over conventional systems prototype evaluation. The ability to introduce man-in-the-loop simulations into SEs is the key benefit for this application area. Predictable and controllable SAF provide most benefit in systems evaluation. There is a need to move to a more Human Science based assessment of individual and team behaviour. It is not essential to provide detailed performance feedback to the operators used to man the simulators as intrinsic feedback will usually provide sufficient information for operator motivation. A full range of operator performance will be necessary to provide the statistical variability that the SE seeks to capture.

Training. Some skills to be trained may have dictated a high fidelity database (e.g. gunnery or target identification) and this will not interfere with the training of tasks that only need a low fidelity database. The interaction between the physical fidelity of the database and the requirements for SAF to be able to utilise their behaviours fully has been noted (e.g. terrain resolution sufficient for dismounted troops to use as cover). The behaviour of SAF can be manipulated to control the training process or make a particular training point (Morrison 1996). Training as an SE application area is least likely to benefit from increased behavioural realism in SAF as it reduces control and increases variability of the SAF response**.**

The performance measurement should be chosen in advance of the training session and be based on the training goals. This choice requires adequate task analysis and doctrinal support. Training can only proceed slowly with intrinsic feedback: After Action Review (AAR) provides relevant explicit feedback that ensures skill acquisition proceeds at the optimum rate. Training is a regular and routine task which will demand efficiencies in its delivery. It follows that sophisticated SEMS are required to reduce the number of training staff and the workload on the trainers.

Table 1: Key human science contributions to SE content and method

SE area	SE content	SE method
Operational analysis	***Requirements*** DB fidelity can be low but relevant to level of analysis and resolution possible in the SE. Constructive SEs will have lower resolution DBs than virtual environments. Typically only low resolution of entity physical models is required, e.g. representations of aggregate forces. Detailed knowledge of the rules underlying SAF behaviours. ***Current contribution*** Simple behavioural models for command agents**.** ***Future contribution*** Entity level behavioural models. Scaleable DB fidelity.	***Requirements*** Detail and breadth of coverage in data capture and analysis (but not for real time). VV&A of all models used. ***Current contribution*** Human performance measures can supplement hard OA measures of hits, kills and exchanges. HS can VV&A behavioural representations. ***Future contribution*** Automated identification, capture, analysis and presentation of measures of individual and team performance.
Systems definition	***Requirements*** DB fidelity must be high where it impacts on the system under evaluation. High object model behavioural and physical fidelity. Simulators will require high physical fidelity. The ability to introduce man-in-the-loop simulation into SEs is the key benefit of this application. SAF with predictable and controllable behaviour. ***Current contribution*** Tailored simulator fidelity. Immersion of individual in SE (DI-GUY). ***Future contribution*** Behavioural Avatars for early man-in-the-loop studies. Full sensory immersion in SE.	***Requirements*** Detail and breadth of coverage in data capture and analysis (but not for real time). A range of operator performance will be necessary to provide the statistical variability that the SE seeks to capture. Intrinsic feedback will usually provide sufficient information for operator motivation. ***Current contribution*** Human performance measures can supplement hard OA measures of hits, kills and exchanges. Evaluation tools for MMI prototypes. Analytical frameworks to evaluate fidelity requirements in simulator design. Usability analysis methodologies. Physiological models of the effects of equipment variables on human performance. ***Future contribution*** Rapid virtual simulator prototyping. HFI/MANPRINT methodology developed for SE. Automated MMI evaluation tools.
Training	***Requirements*** DB fidelity can be low or generic. SAF behaviour must be predictable and controllable. DB must allow full utilisation of available SAF behaviour. Object models need low physical/ high behavioural fidelity. ***Current contribution*** Generation of generic DBs. Fidelity specifications for simulation. Improved SEMS. Training feed back systems for AAR (e.g. EXACT, Kelly et al 1996). Training requirements for OOTW. ***Future contribution*** Augmented reality to support training issues.	***Requirements*** Performance measurement systems and authoring systems (combined as AAR systems). Rapid low manpower SEMS. ***Current contribution*** Structured training programmes (matrices). Above real time training paradigms. Automated and AI aided SEMS to reduce training staff manpower. AI aided AAR systems. Models of skill fade and acquisition for individual manual skills. Modelling training effectiveness. ***Future contribution*** Training cost benefit analysis methodologies. Improved collective and individual behavioural measures for performance assessment and AAR.

SE area	SE content	SE method
		Techniques for distributed AAR. Development of methodologies for team training in SEs. Models of skill acquisition and fade for complex highly cognitive team tasks.
Mission rehearsal	***Requirements*** Rapid generation of very high fidelity DB. SAF with high behavioural variability. Object models with high physical and behavioural fidelity. ***Current contribution*** Fidelity requirements for simulation. SE (VR) team training systems. ***Future contribution*** Full sensory immersion of individual soldiers in SE.	***Requirements*** Rapid low manpower SEMS. Mission based measures of performance. Field-able SE systems. Techniques for distributed AAR ***Current contribution*** Pilot distributed training methodologies ***Future contribution*** Behavioural models of psychological, social and cultural variables for SAF. Team performance measures
Warfare	***Requirements*** DB match fielded equipment. Rapid modelling of DB from intelligence data. Object model fidelity match fielded equipment. ***Current contribution*** Management/Organisational theory. Information warfare. PsyOps. ***Future contribution*** Common MMI for CIS. Real time what-if modelling in SE to support operations.	***Requirements*** Future operations will require continuous performance measurement of man and CIS, and data logging for historical and on-line analysis. ***Current contribution*** Usability engineering evaluations of CIS to reduce operator work load. ***Future contribution*** CIS systems with embedded training systems, contributing to continuous performance monitoring and evaluation.

The need for trainers to be interactively involved during the training process will necessarily increase their workload; however, future intelligent training systems may alleviate this problem area by, for example, automatically referencing relevant doctrine.

Mission Rehearsal. The need to rapidly model a high fidelity database from intelligence data is greatest in mission rehearsal. The requirement for SAF to be able to fully utilise their behaviours has been noted. The physical fidelity of object models should be high and they should have high behavioural fidelity. The behavioural fidelity of SAF contributes greatly to the overall behavioural fidelity of the simulation. There is a need for performance measurement that allows assessment of mission success, but it is not essential to provide the detailed performance feedback used in training. Mission rehearsal requires rapid Orbat and database generation. The management workload must be kept to a minimum as staff for support staff for operational duties will be hard or find or train at short notice. Therefore sophisticated SEMS are required to reduce the staff workload, and future intelligent SEMS may alleviate this problem area.

Warfare. The physical fidelity of the database must match the fielded CIS that the SE is supporting. Rapid modelling of databases from intelligence data is important. The physical fidelity of object models should match the fielded CIS that the SE is supporting. SAF may not usually be required, as intelligence data on the enemy will dictate behaviour. Performance measurement and data logging during operations are likely to be a requirement in future systems. Many lessons have been difficult to learn from recent conflicts because insufficient emphasis was placed (for pragmatic reasons) on record keeping. Management and control of operational CIS must be improved and supported to reduce workload, however future intelligent SEMS may alleviate this problem area.

Priorities and Benefits for Further Human Science Research in SEs

An examination of Table 1 shows that there is much that Human Science can contribute to the development and use of SEs. On the grounds of potential payoff and viability, the priority areas for further research are:

Development of improved behavioural models for SAF

Development of improved performance measurement – especially for team/collective performance

Context/purpose-dependent specification of fidelity requirements in SEs

The requirements for improved behavioural models must be driven by clearer specifications of both their context and purposes, together with a clearer understanding of the degree to which a particular SE application will benefit from such models.

Component models of behavioural variables interactions with tasks and environments will be of great utility, while research into the practicality and real utility of sophisticated behavioural models is carried out.

SUMMARY

Huge resources are being invested in SE technologies in order to provide support throughout the defence process. An important contribution to the effective use of SEs can be provided by the focused input of Human Science. This paper summarises realistic ways in which the human scientist can help to maximise the effectiveness of SEs – both now and in the future.

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ABBREVIATIONS

AAR	After Action Review
ADS	Advanced Distributed Simulation
ALSP	Aggregate Level Simulation Protocol
BBGT	Brigade and Battle Group Trainer
BFIT	Battle Force Inport Training
CAD	Computer Aided Design
CATT	Combined Arms Tactical Trainer (UK)
CCTT	Close Combat Tactical Trainer (US)
CGF	Computer Generated Forces
CIS	Command Information Systems
DB	Database
DIS	Distributed Interactive Simulation
HFI	Human Factors Integration
HLA	High Level Architecture
HS	Human Sciences
I/ITSEC	Interservice/Industry Training Systems and Education Conference
IPME	Integrated Performance Modelling Environment
MANPRINT	Manpower Personnel Integration
MOD	Ministry of Defence (UK)
NCD	National Capability Demonstrators
NTC	National Training Center
OOTW	Operations Other Than War
SEs	Synthetic Environments
SAF	Semi - Autonomous Forces
SIMNET	Simulation Network
SME	Subject Matter Expert
STOW	Synthetic Theatre of War
STRICOM	Simulation Training and Instrumentation Command
TES	Tactical Engagement Simulation
VR	Virtual Reality