Simulation interoperability — where are the challenges?

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ABSTRACT

This paper will discuss and review the nature of simulation interoperability. It will analyse the scope of interoperability in terms of basic intercommunication features (technical interoperability), fitness for purpose (functional interoperability) and suitability for use in distributed training (training interoperability). Only technical interoperability has received close attention, through DIS and HLA standards. Other aspects still present many challenges. The ability to create a common 'outside world' database is frequently cited as the dominant component and principal challenge in any discussion of interoperability. While this is often true, this paper identifies how interactions among all participants in the shared operational space ('battlespace') should be the starting point in defining interoperability, these interactions of course being dictated by the training requirement. Interactions are accomplished through 'sensors', which could be the human eye, night vision goggles (NVGs), radios, data links, radar, FLIR etc. Comprehensive interoperability demands comparable levels of modelling among all participants, including the effect of the environment (whether terrain or meteorology) on the performance of each simulator's sensor suite. The paper will identify these significant effects and discuss where simulation technology is challenged and needs to advance, particularly in the context of mission simulation of future joint (Air/Land/Maritime) operations. The paper concludes with some discussion of the way ahead, including how guidelines based on experience could augment the use of standards.

NOMENCLATURE

AWACS	Airborne Warning and Control System
CGF	Computer Generated Forces
DASS	Defensive Aids Sub System
DIS	Distributed Interactive Simulation
DMO	Distributed Mission Operations
DMON	Distributed Mission Operations Network
DMSO	Defense Modeling and Simulation Office (USA)
DOD	Department of Defense
DTNG	Distributed Network Training Guard
ECM	Electronic Counter Measures
EW	Electronic Warfare
FEDEP	Federation Development and Execution Process
FLIR	Forward Looking Infra Red
FOM	Federation Object Model
HF	High Frequency
HLA	High Level Architecture
ICAO	International Civil Aviation Organisation
IPR	Intellectual Property Rights
IR	Infra Red
LGB	Laser Guided Bomb
M&S	Modelling & Simulation
MLU	Mid Life update
MTC	Mission Training Centre
MTDS	Mission Training through Distributed Simulation
NASMP	Navy Aviation Simulation Master Plan
NEC	Network Enabled Capability

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NVG	Night Vision Goggles
PFI	Private Finance Initiative
ROE	Rules of Engagement
RTO	Research & Technology Organisation
RWR	Radar Warning Receiver
SISO	Simulation Interoperability Standards Organisation
UTM	Universal Transverse Mercator
VHF	Very High Frequency

1.0 INTRODUCTION

1.1 Simulation interoperability

This paper is about *simulation* interoperability. It will discuss the scope of simulation interoperability, how to categorise it, and where there are still challenges.

In the military world, interoperability, a major goal, is defined as;

> *'The ability of systems, units or forces to provide services to and accept services from other systems, units or forces, and to use these services so exchanged to enable them to operate effectively together.' (JSP 110)*

In the simulation community, interoperability may, perhaps, be considered as narrower in scope. But this is debatable, since the natural world and environment have to be simulated, as well as the key *relevant* features of all the participating entities. In the real world, the entities, and the world itself, already *exist*. Only how they work *together* has to be resolved.

Distributed simulation is not just about simulators but also simulation in the broadest sense, using the well-known categories of live (real people using real equipment), virtual (real people using simulated equipment) and constructive (simulated people using simulated equipment), which includes computer generated forces.

1.2 The need

Why is simulation interoperability needed?

In civil aviation, an airliner normally operates well way from all other aircraft, except in the vicinity of, and on the ground at, airports. Indeed, the role of air traffic management is to keep aircraft well apart. Airliners do share airspace with one another, and appropriate voice communications, including interaction with air traffic control personnel, are important components of the training environment. Perhaps, also, more ground traffic, with potential runway incursions and other collision hazards, should be introduced.

The military world is quite different. Military aircraft need to operate closely with others to fulfil their missions. Examples are strike packages in four-ship or larger formations, supported by air superiority fighters, electronic warfare assets and command and control aircraft such as AWACS, together with air-air refuelling,.

Increasingly, joint operations, involving Air assets combining with Land and Maritime force components, are becoming common. Such assets may also be from another nation, in coalition operations. Training in such complex national and multi-national conditions is very demanding. Live exercises, the traditional mechanism for such training, are becoming too expensive or even impractical. Simulation has to take their place. Fortunately, simulation technology has developed sufficiently in recent years that it can provide realistic and demanding simulated mission environments for collective (multi-participant) training. Advanced distributed simulation is being used, therefore, in complex mission training, or is being looked at as the potential solution.

Can simulation technology, however, meet all these expectations? Can it deliver re-configurable training systems capable of working with other training systems, possibly over wide area networks, to serve collective mission training needs in an era of network enabled capability? This is the essence of the simulation interoperability challenge, and why it matters.

1.3 Experience to date

Simulators have been networked together since the first major networked training simulation, the SIMNET programme created for the US Army in the early 1980s[1]. Interoperability issues were addressed then by using the same technology in all simulators involved. It was soon realised that, in the long term, this was impractical and the discussion of simulation interoperability began with the establishment of the Distributed Interactive Simulation Workshops and subsequently the more general simulation interoperability workshops (see *www.sisostds.org*).

Since that time distributed simulation and simulation interoperability have developed enormously. Significant progress has been made in the technical areas of networking and getting simulations to work together at a basic level (using DIS and HLA – see below). Today, the US Air Force has its own evolving system[12], known as Distributed Mission Operations (DMO), with many Mission Training Centres (MTCs) in operation world-wide, including at RAF Lakenheath, in the UK. Other nations are pursuing a similar capability, partly stimulated by the NATO simulation experience of networked coalition air operations through 'First WAVE'[19], as has been described at earlier RAeS conferences[22]. Some lessons from recent UK experiments in Mission Training through Distributed Simulation (MTDS), using the capability concept demonstrator, are described elsewhere[17] at this conference. Despite the progress already achieved, there are still many challenges to be addressed to ensure that simulations can be networked and operated together to deliver a truly *usable*, affordable and realistic training environment.

2.0 SCOPE OF SIMULATION INTEROPERABILITY

2.1 Scope

In discussing simulation interoperability, the simulation categories of interest are not only virtual (the classic piloted flight simulator), but also constructive (in the form of computer generated forces) and increasingly live, including aircraft and other platforms as well as other real equipment such as command and control.

Achievement of simulation interoperability calls for progress in many areas, both technical and organisational. A current major study on Simulation Interoperability Requirements and Enablers (SIRE), set up under the UK MoD SE towers of excellence programme and being conducted by an industry consortium, has identified a top-level list of interoperability themes as a basis for evaluating simulation interoperability. These ten themes are:

- Synthetic Environment (SE) management
- SE processes and supporting infrastructures
- SE models and toolsets
- policy
- architectures
- standards
- training and skills
- supply chain
- security and IPR

This paper deals mainly with issues of technology affecting simulation interoperability: models, interactions, architectures and standards.

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2.2 Purpose

Interoperability is not just about connecting simulators together across a network, and the necessary data exchanges and data interfaces. It is much more about the resulting whole system being suitable and fit for purpose. This involves answering such questions as

- *what* does the user want to do?
- with *whom* does the user want to operate?
- *where* geographically does the user want to operate?
- under what particular *circumstances* and with what particular *emphasis*?
- what are the main (training, mission rehearsal etc.) *objectives*?

The key features implicit in these questions define the interactions needed between all the elements of the total simulated or synthetic environment in the shared operational mission space ('battlespace').

2.3 Key factors

Any entity, such as an aircraft in flight, a tank moving on the ground or a ship at sea, is aware of the presence of other entities only via a number of sensors. These can include the human eye, as well as such devices as voice communications, data links, radar or thermal imaging. Thus, the first key factor in simulation interoperability is the representation of *interactions between entities*.

An entity and its sensors will be affected by the environment, whether it is air temperature on engine performance or weather (e.g. rain) degrading the behaviour of a sensor. This is the second key factor: *environmental effects on entities* and their interactions.

An entity can have a direct effect on the environment, perhaps through inflicting damage on a bridge, by emitting smoke or triggering tracks or dust on the ground. This is a third key factor: *effects of an entity on the environment*.

Considering just air operations will yield one list of potential interactions. Analysis of land and maritime operations will yield further lists. Many additional complexities arise when the domain of interest expands to include combinations, such as air with land, air with maritime or air with land and maritime.

2.4 Entity interactions with other entities

Entities and their interactions only exist in a simulation through their representation in models and data. These models and their supporting data define and constrain interoperability. If there is no model, that aspect or feature is absent from the simulation and therefore unable to respond to an external influence, giving no interaction.

A simulation of an aircraft and its systems will contain many models (Fig. 1). Some of the models will deal with the aircraft as a platform: its aerodynamics, engines, flight control system. Many other models will represent the aircraft's mission systems: communications, weapons, sensors, EW, defensive aids. These are the components that affect the aircraft's interactions with other aircraft (and with other entities in general).

These sensor systems operate across the electro-magnetic spectrum, ranging from visible light, through infra-red (with its different bands used for different purposes), to radar and radio (UHF, VHF and HF). The human eye senses reflected energy, therefore a source of illumination is needed: the sun, the moon, lights. Night vision aids may use image intensifier technology or thermal infra-red (IR). IR devices sense radiated energy and are therefore passive, needing no illuminator, but do need to know the thermal history of an object and its surroundings. Modelling of an IR system needs to take account of the quality of the on-board sensor. Radar in its various forms (air-air, ground mapping, synthetic aperture) transmits signals and receives energy reflected from objects or from the environment.

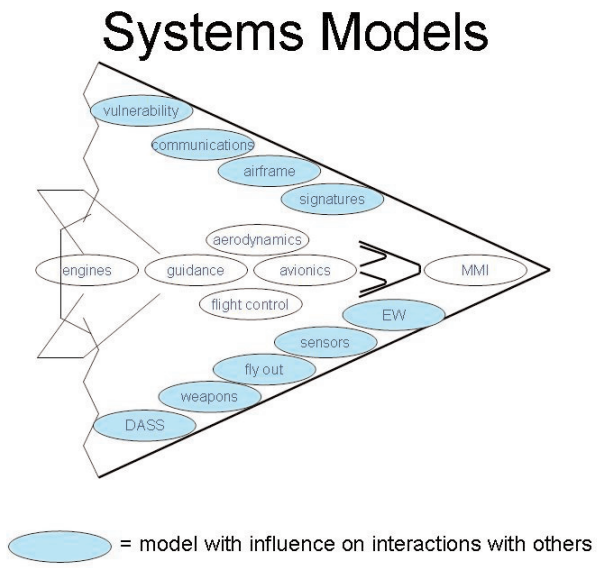


Figure 1. Aircraft and system models.

Representation of the geophysical and cultural environment (terrain, ocean, atmosphere) through 'databases' usually needs to include not only the visual form and appearance but also sensor-specific attributes (reflectivity, emissivity, multi-spectral). Night vision aids respond to ambient illumination (full moon to starlight to no moon with total overcast). The database and rendering process therefore needs to include a variety of effects: self-luminant areas (eg lighted windows), ambient light effects on clouds, reflection of moon or stars over water, search light effects, blinding (saturation) of the sensor. The environment must also include representation of the battlespace components defined by the tactical scenario.

A Defensive Aids System will include passive countermeasures (radar and laser warning receivers, missile launch warning, missile approach warning), all reacting to the complete emitter environment of the tactical scenario, both surface-based and air-based. Achievement of interoperability needs an agreed 'library' of sources. Active countermeasures include decoys, chaff (to confuse radar), and flares (for IR seekers).

Weapons must model appropriate phases – detection, recognition and identification of targets via ownship sensors (visual, radar, IR), target acquisition, target tracking, weapon release, fly-out, damage effect at target – all in response to external influences eg movement of the target, and its use of defensive aids.

Damage modelling is a challenging area in simulation interoperability. Damage assessment methods and models can vary widely. Each federate needs to know about specific munitions it is likely to encounter (otherwise detonations would be ignored) and must have damage tables (or some other process) for those specific munition/target pairings, in order to be able to report detonation results. This is a difficult area to verify.

2.5 Environmental effects on entities and their interactions

Ambient conditions such as the time of day or night, the level of illumination, the state of the atmosphere and the weather provide the dominant environmental effects. Broad effects are determined by the geographic region of operation and the local climate.

A standard ICAO atmosphere relates pressure, temperature, density as a function of altitude. The standard used must be

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appropriate to the area. Local 'hot and high' conditions have a significant effect on platform performance, reducing thrust and lift and therefore an aircraft's mission payload and range. Do all collaborating simulators even use a common standard atmosphere?

In the real world, meteorological effects on aircraft have been categorised[16] as winds, temperature, humidity, icing, visibility and runway conditions. Winds, including turbulence, thunderstorms, storm cells, and wind shear in three-dimensional form, affect an aircraft's flight path. Temperature and icing affect an aircraft's performance, in such ways, for example, as the payload that can be lifted from a given runway or the turn performance that can be achieved. Visibility embraces cloud cover, fog, precipitation (rain, snow, hail), dust, smoke and their effect on target identification and any targeting constraints dictated by the rules of engagement (ROE). Visibility affects human vision as well as the response of such on-board sensors as TV or FLIR. Runway conditions include accumulation of rain or snow.

Weather can be static or dynamic: evolving over time and space in a coherent, physically-plausible manner, such as through the progress of a front; but weather simulation still needs to be under control, otherwise the situation can occur that 'all runways are fogged in', as happened, a little to the surprise of some participants, in one recent simulation.

IR images are affected by the radiant source and by the local environment (air temperature etc); by transmission through the atmosphere, with attenuation affected by humidity, rain, wind, and haze.

Interoperability issues arise from the desire to have correlation and coherence across the federation. Is it possible, for example, to define the atmosphere and weather to all participating simulators? Then there is the question: what do they then generate? Local generation of clouds will inhibit interoperability as information about their precise shape and form will not be sharable.

2.6 Entity effects on the environment

An entity can have a direct effect on the environment in many ways. Aircraft and their weapons can generate exhaust plumes and smoke trails, ground vehicles can leave tracks and raise dust, rocket launchers and artillery can also create smoke and trails, while ships can generate wakes and waves. Damage to runways, buildings and structures, or just to terrain, needs to be shown. Defensive aids, such as decoys, chaff or flares, are visible, and their movement needs to be shown as they are affected by local wind and as they disperse with time. Smoke may be generated as a deliberate obscurant or as a signal in a variety of colours.

As Joint Collective Training events, involving different services (or even coalition partners) operating together, increase, the variety of such effects will grow. While simulators used in one domain (air, say) will typically be capable of representing the common phenomena of their domain, combining new domains will introduce new requirements and challenge interoperability once more.

3.0 SIMULATION INTEROPERABILITY OVERVIEW

3.1 Definitions

M&S Interoperability has been defined[10,11], based on the JSP definition given earlier, as

> *'The ability of a model or simulation to provide services to and accept services from other models and simulations, and to use the services so exchanged to enable them to operate effectively together.'*

The creation of Distributed Interactive Simulation (DIS) standards[6-9] in the early 1990s, and then of the High Level Architecture (HLA) a few years later[13,14] tackled some fundamental issues in information exchange for simulation interoperability. However, it was soon realised[3] that these standards addressed only the issues of intercommunication, now often referred to as technical interoperability. Achieving technical interoperability using HLA (or DIS) ensures that a federation will execute but '*does not guarantee the creation of a meaningful federation application*' and says nothing about '*the adequacy of the federation to accomplish its mission*', ie whether it meets the users' needs.

These broader aspects of interoperability were recognised under the label of 'substantive' interoperability. Thus Dahmann found it helpful to distinguish two levels of simulation interoperability[3]:

> ***Technical interoperability****: the capability of federates (e.g. simulations) to physically connect and exchange data through those connections.*
>
> ***Substantive interoperability****: the capability of federates, when connected, to provide adequate, accurate and consistent simulated representations that adhere to the principles of 'fair fight' and address the mission objectives.*

Interoperability requirements can also permeate much wider, into procurement processes and industry, if the long term objective is to *design* for interoperability.

Some writers prefer to distinguish between simulation interoperability as dealing solely with technical issues, while 'composability' concentrates on modelling. Composability has been defined as[20]:

> *'**Composability** is the capability to select and assemble simulation components in various combinations into simulation systems to satisfy specific user requirements. The defining characteristic of composability is the ability to combine and recombine components into different simulation systems for different purposes.'*

A recent RAND study[5], sponsored by the US Defense Modeling and Simulation Office (DMSO), has provided a comprehensive overview of composability for future US military simulation systems. Its findings, also summarised in a short paper[5], have broad applicability. Other writers at the Virginia Modeling Analysis and Simulation Center[21] have developed a model (the 'levels of conceptual interoperability model') with seven levels, ranging from Level 0 – Stand-alone systems with no interoperability through semantic, pragmatic and dynamic interoperability levels, to Level 6 – Conceptual Interoperability, where models are fully documented based on engineering methods, and demonstrate fully aligned assumptions and constraints.

3.2 Technical interoperability

Bringing together a set of simulators and simulations calls for new requirements. It is convenient to adopt the (HLA) terminology of federates (simulations and supporting tools) and federations (an integrated collection of federates brought together for a particular purpose).

What is required to achieve a federation? Obviously, multiple 'network capable' simulators must be available, either in a local group (likely to be to the same technical standards) or located remotely (almost certainly dissimilar). They need to be linked via a communication network (local or wide area), and have software to enable information to be exchanged among the players. Such information exchanged among the entities will answer such basic questions as:

- what am I? (aircraft, tank – perhaps with articulation, for a turret or swing wings)
- where am I? (position, attitude, speed/direction)
- what am I doing? (that matters to others, such as transmitting (radio), emitting (radar), or firing a missile)

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To meet these basic requirements of 'connect – exchange – understand', the simulation community defined and implemented the widely used Distributed Interactive Simulation standards[6-9], supported by enumeration guidance. Expansion of the need, to widen simulation applications from being platform-based to include constructive simulations and live equipment, led to the High Level Architecture[13] and supporting processes such as the FEDEP[14]. The High Level Architecture has also been widely adopted.

These standards address interconnection, but interconnection is not the same as, and is no guarantee of, interoperability. Many issues remain to be solved. A recent paper[2] describing the building of the Joint Experimental Federation, to serve the exercise known as Millennium Challenge 2002, summarises many valuable lessons learned in the creation of a very large federation (more than 34,000 battlefield platforms), using both DIS and HLA. Ceranowicz described the process of building a federation from existing federates as '*primarily one of reconciling differences in the philosophy and implementation of the simulations involved*'.

One particularly interesting question that had to be resolved was whether to use aggregate or entity representations in an overall simulation with its main interest more on the operational level of warfare, rather than tactical. The deciding factor – and an important lesson – was that a primary focus of the experiment included surveillance assets, which detect individual entities not aggregates, and so to use entities made more sense. A further important lesson was that developing a common set of enumerations and making sure that they are implemented in each simulation requires considerable patience and constant attention. This emerged also in the NATO First WAVE experience[19].

Once simulators are connected and shown to work together at a basic level, a common terrain database is often identified as the next critical requirement. This may not be the case. Generation of a common terrain database is expensive and time-consuming. The key drivers must be the training need and the consequential interactions. It may be that only some simulators (a strike aircraft and a Forward Air Controller, or Joint Terminal Attack Controller for example) need a common database, and then perhaps only of selected target areas but in high detail. The US Navy Aviation Simulation Master Plan Interoperability Standard has recognised that 'interoperability does not demand identical databases'.

Entities sharing the same battlespace need to have a common coordinate system if they are to be able to define their relative locations and to operate against a common target area. It is surprising to find just how many coordinate systems exist. Fortunately, the SEDRIS programme (*www.sedris.org*), through its Spatial Reference Model, has addressed this issue, identifying 151 spatial reference frames but also developing supporting coordinate conversion software. Thus, as well as the databases available, it is also important to identify how the terrain is represented, and particularly the coordinate system used: eg geodetic, flat earth, UTM.

3.3 Functional interoperability

Functional or substantive interoperability is concerned with establishing whether the purpose of the overall simulation event can be met by the proposed federation. It is a semantic issue: will the models in all the component federates interact realistically to provide the right training experiences? Is the federation 'fit for purpose' in its defined context? It is difficult to answer these questions except by detailed testing. There are no established methods and tools to address the issue. One method is for the user community to define a scenario and create a scenario narrative – a 'conceptual model' – outlining the evolution of a typical mission and the main actions and events that could happen, particularly regarding the use of communications, sensors, weapons and defensive aids. This will help identify likely interactions and enable the technical experts to review their own simulations and highlight possible areas of concern. This would be an iterative process, to reconcile user needs with simulation capability.

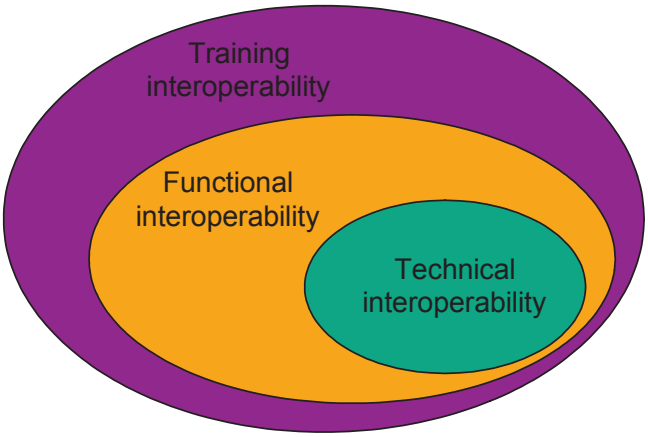


Figure 2. Layers of Interoperability.

Widening the Service domains of use for distributed simulation, from Air, to Air and Land, Air and Maritime and ultimately all three – Air, Land and Maritime – will challenge simulation interoperability in two major ways. First, there will be a need to ensure communication and understanding in all the user and technical communities. Secondly, simulation technology must be able to meet the extra demands of the wider battlespace.

If collective training and mission preparation are the top-level goals, these should be feasible but if issues of 'mission rehearsal' could arise, there may be significant implications for the validity of any overall federation.

3.4 Training interoperability

Achieving technical and functional interoperability among simulations will together provide the core capability of an interoperable federation, but to meet the training requirements of the multiple users introduces an extra layer (Fig. 2) of interoperability – training system or distributed training interoperability – to provide all the facilities and capabilities needed by the staff and participants to enable them to conduct multi-user distributed training exercises.

Further aspects of interoperability involve the user communities, national and coalition, the procurement authorities and industry.

To achieve training interoperability requires facilities for the participants, including rooms in which to work and tools to support planning, briefing and de-briefing with local and distant colleagues. They may also want to be able to bring with them, and use, their own mission planning systems.

An overall exercise management facility is needed, with tools and facilities to enable exercise management staff to control, supervise and, after the event, replay and review what happened.

3.5 Computer generated forces

Computer Generated Forces (CGF) are an essential element to populate the tactical environment and augment the numbers and capability of both blue and red forces. This is one of the areas of simulation technology with least interoperability today, largely because proprietary software packages are used.

To create CGF calls for each entity to be defined in terms of its performance, the physics-based aspects of manoeuvring and the capabilities of its sensors and weapons. Each entity also has to be defined in terms of its behaviours in responding to other entities

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and to the environment. Operational doctrine has to be captured as well as the response of the computerised 'crew' or operators.

Considerable amounts of data and supporting information have to be captured, usually from military subject matter experts, validated and then embedded in the CGF software packages. There are no standard ways to do this and, once captured and embedded in the software, there are no ways to exchange and re-use such data.

To tackle these issues, common CGF software is being developed, such as the US Army's One Semi-Automated Forces (OneSAF). Until such common packages are widely used, however, there will be many outstanding challenges.

So far, this discussion has considered the *internals* of CGF software. For use in a distributed simulation environment, there are additional requirements. These include being able to set up initial positions, and agreed routes, across the whole federation. Exercise control staff will also want to be able to supervise the broad behaviours and locations, possibly making changes as an exercise evolves, in order to achieve maximum training benefit. Not all CGF packages provide appropriate levels of control and ease of use.

4.0 SIMULATION INTEROPERABILITY CHALLENGES

Successful achievement of a particular simulation federation will depend on the details of its configuration. There are, however a number of steps that could be taken to improve the likelihood of success.

4.1 Enablers

Any future training federation involving geographically separate network-capable (and potentially interoperable) training systems will need access to a number of elements that come under the heading of 'infrastructure'. These include

- a managed and readily–available secure wide area network
- well-defined security accreditation processes
- common computer generated forces, to boost numbers of entities in both blue and red forces
- environmental database generation facilities, capable of augmenting existing databases and with the potential to generate a common and re-usable database of a new area of the world, suitable for all sensors, not just the human eye
- Exercise management facilities and tools

4.2 Policy (Limiters)

Interoperability challenges are not just technical. Indeed, many involve policy issues and the culture and ethos of organisations, and may be more difficult to resolve than the technical issues.

- Security
- IPR and other commercial issues such as result from the widely-employed PFI contracts. The desire for commonality may be contrary to commercial imperatives
- Future procurement processes, to include comprehensive documentation and provision for the re-use of models

4.3 Science of interoperability

It has been pointed out by Windyga *et al*[23] that there is no 'unifying theoretical or practical framework for formally describing interoperability'. The paper also concluded that development of such a framework 'faces at least two challenges: properly enumerating and describing all relevant simulation attributes, and developing a method for combining the evaluations of these attributes into an overall meaningful interoperability rating'. The science of interoperability needs to be developed, to include a method to define the user's requirements so that they can be analysed to reveal the demands they place on simulation. To match this, there is a need to document and characterise simulations to identify what is modelled, and how it is represented, again to foster analysis, and to address the challenge that models and their internal algorithms can severely inhibit interoperability. Without some formal, analytical mechanism to relate requirements and simulation capability, the only process is to rely on the knowledge and experience of the simulation practitioner and the military subject matter experts.

Considerable detail may be necessary. For example, for a sensor of type XX, it would be necessary to address such questions as:

- How does sensor device XX work (in broad terms)?
- What data does the sensor require eg terrain material properties?
- What can degrade its performance?
- Are such features present in the (total) simulation?

During the development of the First WAVE networked real-time simulation of Combined Air Operations[19], the creation of interaction tables was found to be a helpful technique to support preliminary and detailed analysis of compatibility. The matrix example below focuses on the F-16 MLU platform entity and the possible interactions that are likely to take place between the F-16 MLU simulator and the simulated F-15. The horizontal row lists the F-16 MLU interactive components, whilst the vertical column lists the F-15 interactive components. An X in any column indicates that an interaction is likely to place between the F-16 MLU simulator and the entry listed under the left-hand column. This then triggers a discussion of the nature and quality of that interaction.

Table 1
F-16 MLU

F-15	Entity	Radar	RWR	Chaff	Flare	AIM –120	LGB	AIM –9	20mm
Entity	X	X			X	X	X	X	X
Radar	X		X	X					
Chaff	X	X				X			
Flare	X							X	
WR		X				X			
AIM-120	X		X	X					X
AIM-9	X				X				X
20mm	X					X		X	

This kind of table could be extended to deal with interactions between sensors and the simulated environment, as indicated in the partial example below;

Table 2
Sensor type v Environment

	Terrain	Cloud	Rain	Smoke	Thermal History
Radio (HF, VHF, etc.)	X				
Data Link	X				
Radar	X				
NVG					
FLIR	X	X	X	X	X
RWR					
Sonar					
Other ECM					

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This is not complete. Other interactions may be identified, such as the effect of trees on FLIR performance.

Further extension is possible, to address sensors and countermeasures.

Table 3
Sensor Type v Countermeasures

	Chaff	Flares	Jamming	Lights	Smoke
Radio (HF VHF, etc)			X		
Data Link			X		
Radar	X		X		
NVG					
FLIR		X	X	X	
RWR					
Sonar					
Other ECM					

There is a need for more documented experiences of interoperability issues and how they were overcome. This has been done for First WAVE to some extent[19]. Experiences building the very large Joint Experimental Federation[2] have been well summarised. A particular point to emerge from that project is that verifying the effect of munitions needs the help of automated tools. Ceranowicz describes the use of a special (and very useful) feature to provide a mode in which detonations produced damage assessments but did not actually implement any damage and so avoided the need to replace damaged vehicles during testing.

4.4 Training systems

Candidate training systems for future large-scale federations need to be identified and preliminary documentation produced, identifying such features as the main simulation components, the tasks for which the system was designed, the level of security at which the system operates, the models employed and the provision of computer generated forces. Any exercise control mechanisms also need to be listed.

5.0 SECURITY

One of the biggest, and largely non-technical, challenges to simulation interoperability (and indeed to operational interoperability) is security. This is true even within a single nation, where different synthetic training systems are likely to have different levels of classification. They will not be allowed to interconnect without either the higher level system being down-graded (by choice of data or even by modelling changes) or the lower level system being upgraded. Systems of similar (high) level of classification have still to be accredited by an appropriate Authority before they will be allowed to interconnect. Staff involved in such accreditation processes need help to understand the needs and capabilities of simulation.

If coalition training is the goal, then additional multi-national issues arise. Secure, multi-national simulation has been achieved successfully, such as in the First WAVE project[22], but still not without difficulty. First WAVE revealed the extent of these challenges[19].

Security approval and accreditation has to identify all the simulation participants and their roles and interactions, and reflect the need for information disclosure. The same methods used to assess interoperability issues among potential collaborating systems can also help in assessing information disclosure.

Senior military and civilian staff need to be more aware that security issues can be a 'show-stopper' in networked simulation for coalition training, and give serious attention to tackling these sensitive issues.

The US Air Force is actively exploring technical solutions for multi-level security[4], involving a Distributed Network Training Guard (DTNG), a system with both a trusted guard to manipulate data and a separately hosted security rule set support tool. However, this review states that, while the '*assessment has identified nothing that would preclude the use of the DTNG in the Combat Air Force distributed mission operations environment, at the same time there are considerations that indicate a current immaturity of the guard with respect to its overall viability for the DMON*'.

6.0 WAY AHEAD

Simulation interoperability matters but has weak foundations in science and technology. A number of steps could be taken:

- capture and report experiences and lessons learned in creating successful (and unsuccessful) federations
- formulate check-lists and guidelines for best practice
- develop ways to describe applications and to characterise simulations in order to be able to analyse and assess 'goodness of fit'
- ensure future procurements include requirements to foster simulation interoperability
- document, at a high level, legacy simulations – likely to be with us for many years – that are candidates for use with others to build larger federations
- identify these candidate mission training systems and initiate their preparation for use

Simulation interoperability matters not only in the world of mission and collective training, but also in system design, test and evaluation and use in preparation for operational deployment. Network Enabled Capability (NEC) will foster this convergence.

7.0 CONCLUDING REMARKS

We have been connecting simulations and simulators together for more than 20 years but some of the fundamental issues of interoperability are still unresolved.

In the military world, stand-alone simulators and training systems are widely accepted. However, operational realities and the evolution of Network Enabled Capability now place greater emphasis on flexible formations and coalitions. Consequently, collective and joint collective training are becoming more and more important. This growing need to compose complex synthetic environments from hitherto separate training systems demands that the issues of interoperability be fully recognised at the highest level and that resources be allocated so they can be addressed. These issues are technical and organisational. Indeed, the organisational issues (including security, IPR and procurement processes) may well be the most difficult to resolve. Technically, an infrastructure needs to be established, including a managed and readily–available secure wide area network, common computer generated forces, environmental database generation facilities, and exercise management tools. Simulations must be able to operate and interact across the full electro-magnetic spectrum, not just the visual representation of the battlespace. Combining the Air, Land and Maritime domains will introduce new challenges.

Simulation interoperability matters. It is achievable, but it takes significant effort. Interconnection is not interoperability, just the first step. Specification and use of DIS or HLA standards are necessary but not sufficient. Common environmental databases are also important but are not the starting point. As ever, user requirements establish what is needed, with emphasis on the interactions between all the likely participants. Customers – those who pay for and hope to see the benefits of simulation interoperability – need help to have realistic expectations and to define achievable requirements.

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Generating joint collective training systems by interconnecting existing facilities will be possible but challenging. It should not be imagined that this can be accomplished rapidly. Many months of intense effort will need to be devoted to integration and testing, with the close involvement of the end users. To establish a complex synthetic environment in weeks rather than months – and so meet expectations stimulated by network enabled capability (NEC) – is likely to be achievable by reviving and adapting something that has already been done. This suggests that some of the obvious combinations should be brought together before the final requirement is completely clear. Inclusion of live systems, especially components of the operational command and control chain, is of growing interest in the context of network enabled capability, and brings its own challenges.

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