Simulating the Future Operating Environment for Training and Education

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ABSTRACT

Military operations are performed in an increasingly complex world where the behaviour of force elements is affected by the state of the natural environment, political effects and social effects, in addition to physical (kinetic) warfare effects.

Modelling and Simulation (M&S) systems have a limited representation of these aspects, and mainly provide static representations of the natural environment and physical warfare effects. The effects of electronic and information warfare such as offensive and defensive cyber and the use of social media as an influence tool are of increasing importance to military users. Current synthetic based training systems employ a component known as Computer Generated Forces (CGFs) to represent the majority of human and systems behaviour as an integral element of the simulation and/or Synthetic Environment (SE) used to deliver the training. However, no single CGF adequately represents the breadth of system, human, organisational and social behaviours that occur in operational environments, and often more than one CGF needs to be employed which were not designed to be interoperable which impacts the ability to provide consistent representation of effects across dissimilar simulation systems. This is a capability gap identified by previous research carried out by the UK Defence Science and Technology Laboratory (Dstl) in partnership with supplier organisations. Related to this issue, "Simulating Future Battlespace Complexity" is one of five UK Defence Innovation Priorities published by the UK MOD.

This paper describes research conducted by the UK Defence Science and Technology Laboratory (Dstl) into the representation of Future Operational Environments (FOE) in Simulation (FOESim). This is aimed at investigating methods and technologies relevant to representing the increasing complexities of operational environments in simulation in a more coherent and effective manner. The scope of this research includes,

- *assessing opportunities for M&S to provide more efficient and effective training in Future Operating Environments (FOE);*
- *new approaches for the composition of more coherent and improved representation of human and systems behaviour across simulation systems;*
- *the representation of warfare effects on current and emerging operating domains such as space and cyber, including non-physical force behaviours such as electronic and information warfare effects;*
- *consistent representation of dynamic natural effects such as weather and terrain on operational environments;*

ABOUT THE AUTHORS

Matthew Smith is an analyst at the UK Defence Science and Technology Laboratory (Dstl) in Training and Transformative Technologies Team. He graduated with a first class BSc (hons) in Games Design in 2015 where he specialised in virtual training simulation and realism. His current work focuses on the representation of the future operating environment for simulation (FOESim) and the exploitation of games development software for simulation as part of Dstl's Transforming Training, Education, and Preparation Project.

Neil Smith is a principal analyst at the UK Defence Science and Technology Laboratory (Dstl). He has over 45 years' experience in real-time simulation research activities, including the use of federated (distributed simulation) systems for defence training, mission planning/preparation, concept development and experimentation, support to defence acquisition programmes, test and evaluation. He is currently working as the Technical Lead for research into the representation of the Future Operating Environment in Simulation (FOESim) which is part of Dstl's Transforming Training, Education, and Preparation Project. This work is investigating processes and technologies aimed at achieving greater coherence and improved representation of operational environments and effects across defence synthetic based training systems.

1.0 INTRODUCTION

Military operations are performed in an increasingly complex and uncertain world where non-physical warfare effects such as cyber, electromagnetic and information warfare are playing greater roles in manipulating the battlespace in conjunction with current physical (kinetic) warfighting methods [1,2]. Simulation and Synthetic Environments (SSEs) have limited support for representing these effects which impacts defence capabilities in the use of synthetic based training systems. This was identified by previous research carried out by the UK Defence Science and Technology Laboratory (Dstl) in partnership with supplier organisations [3]. Furthermore, the UK Ministry of Defence (MOD) has identified the challenges of simulating the future battlespace complexity as one of top five innovation priorities for defence [4]. In doing so, UK MOD has recognised the need for more effective and efficient composable synthetic training environments.

Figure 1: Examples of Simulated Operating Environments and Effects

The employment of SSEs for defence applications including joint and combined (coalition) training and mission preparation will need to represent future operational environments in a more coherent and timely manner, to provide more efficient simulation delivery and support a wide range of effects in the operational space. As an example, Electronic Warfare (EW) and Information Warfare (IW), Cyber and the use of social media as an influence tool are becoming an important factor to defence operations and military decision makers. As IW becomes an increasingly central part of military operations, SSEs will need to evolve to represent it. However, the information environment and information effects are by their nature ambiguous and difficult to simulate, especially as they are driven by human behaviours and thought processes.

In order for military commanders to train in the future operating environment, it is important to provide evidence for the requirement to represent a wider spectrum of effects to meet challenge that will be presented by the future operating environment. This will include investigation into approaches for integrating emerging non-physical effects with physical force and natural environment effects as part of dynamic simulated environments within which forces can manoeuvre, implement, and respond to effects in operational environments.

This paper describes research being conducted by the UK Defence Science and Technology Laboratory (Dstl) into the representation of Future Operational Environments (FOE) in Simulation (FOESim) in a more effective and coherent manner. The research is investigating methods and technologies aimed at informing improved and more agile composition of SSEs beyond those currently being delivered which support a limited range of scripted effects of weather and physical (kinetic) warfare effects on operational behaviour.

This objective of this research is to benefit UK MOD by informing Policy and Strategy to achieve increased Force Readiness through the use of improved joint and combined (coalition) synthetic training systems which can be composed to represent the FOE in SSEs in a more timely, agile and consistent manner across defence.

Key recommendations and outputs from this research will consider how future SSE capabilities can be developed in accordance with the UK approach to Defence Modelling and Simulation Coherence (DMaSC[1]). This includes the provision of common, shared enablers in order to maximise the utility of Modelling and Simulation (M&S) to enhance defence operational capabilities. The work will also consider the composition and deployment of SSEs in line with the NATO Modelling and Simulation as a Service (MSaaS) approach [5].

2.0 SCOPE OF RESEARCH

UK Defence Science and Technology (S&T) research over the next 3-4 years will include studies into the representation of FOE in Simulation. Specifically this will investigate methods and technologies to improve the simulation of people, institutions, and systems (and the collaborative and adversarial behaviours between them), in order to represent a wider spectrum of operational effects and the complexities of future environments in SSEs. This work is an element of the Dstl Transforming Training Education and Preparation (TTEP) Project that forms part of the Future Workforce and Human Performance (FWaHP) Research Programme.

Current synthetic based training systems do not support all of the factors that future decision makers will need to consider, including the effects that would result from these decisions, or complexities of these environments, i.e. the '5Cs' described by the Defence Capability Development Centre (DCDC) [1].

- **Congested** – historically, in a conventional context, Defence Forces have usually sought to avoid a congested battlespace when trying to achieve freedom to manoeuvre.
- **Cluttered** – which leads to an inability to distinguish individuals, items or events, particularly in congested environments, provides the opportunity for concealment and will confound most Western sensors.
- **Contested** – adversaries will contest all environments where they seek to deny our freedom of manoeuvre.
- **Concealed** – military activities including both red and blue forces will continue to gravitate towards the inter-connected nodes.
- **Constrained** – in the complex battlespace of the future 'Western' legal and societal norms will place continued constraints on the conduct of operations.

Research already conducted has delivered two scoping studies [6,7,8,9] aimed at identifying areas of importance relevant to FOESim. These studies concluded that several key themes need further investigation. These include improving the representation, interaction and effects of human and autonomous systems behaviour, representing Hybrid Warfare behaviour such as cyber and social media effects, and the use of SSEs to represent complex urban environments for training.

Ongoing research into simulating the future battlespace includes two activity areas that will inform the development of more timely and coherent SSEs so that they can be composed and deployed in a more agile manner. This will contribute to increased 'Force Readiness', enabling the employment of new capabilities in simulation and will lead to a more efficient and effective use of simulation, including training for joint and combined (coalition) operations.

[1] DMaSC provides a UK Defence wide coherent approach to provide better Modelling & Simulation (M&S) capabilities and reduced costs with less of an environmental impact.

1) People and Autonomous Systems – this activity is focussed on methods for improving the representation and composition of human and autonomous systems behaviours and the effects of operational environments on behaviour, e.g.

   - Composition and deployment of Computer Generated Forces (CGFs);
   - Improved scope and coherency of behaviour representation;
   - Operational effects and interactions between human and autonomous systems behaviours;

2) Future World – this research activity will include studies to address the representation of the future battlespace and emerging warfighting domains in simulation systems, e.g.

   - Representation of smart, large urban environments ('megacities'), including the complex physical, information and cognitive networks;
   - Simulation of emerging domains including Contested Electromagnetic Activities (CEMA), Information Warfare (IW), Cyber, and Space;
   - Consistent representation of the natural and physical environment including dynamic weather and terrain;
   - Development of Use Cases to inform a M&S approach to representing the future world;

2.1 Representation of Human and Autonomous Systems

2.1.1 Composition and Deployment of Behaviour

CGF constructive simulations are an integral element of synthetic based training systems used to represent the majority of behaviour. Given the challenges of sustaining through life support, traditional use of Government-Off-The-Shelf (GOTS) CGFs is being addressed through the increasing employment of Commercial-Off-The-Shelf (COTS) CGF systems. However, in many cases no single CGF adequately represents the breadth of platform, human, organisational, and social behaviours that occur in operational environments, which often results in more than one CGF is employed. Furthermore, the simulation of operational effects are often implemented in a pre-scripted manner in a given CGF, which affects the ability to provide consistent representation of effects across distributed simulation systems due to the bespoke representation of effects.

One of the longer-term visions of the Dstl research is to inform methods to develop a capability for composing and deploying a CGF either as a 'service' or integrated with a local simulation, based on a set of "disaggregated" behaviours. Figure 2 presents a roadmap for the evolution of this CGF deployment over the next 10 years, which also outlines two intermediary stages (i.e. "rationalise", "distil"). The objective is to provide a more agile mechanism for representing human behaviours, institutions, social systems and the increasing number of autonomous platforms that will require representation in future SSEs. Some of the activities currently being undertaken as part of NATO MSG [5] that aim to advance and promote the operational readiness of MSaaS are a key enabler for delivering this vison.

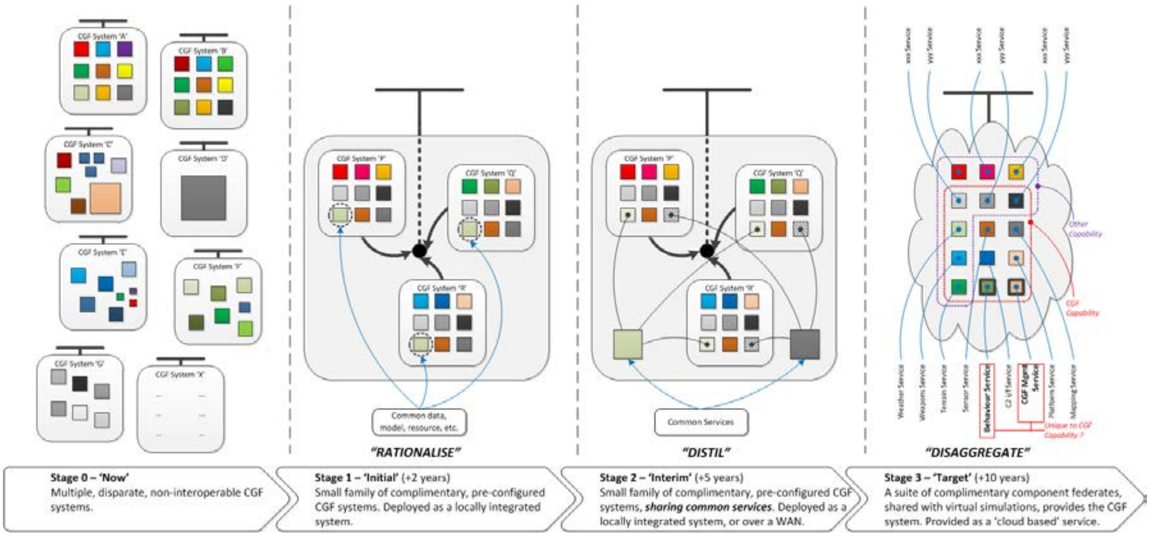

Figure 2: Example of a modular 'composable' CGF Architecture [10]

2.1.2 Consistent Representation of Human and Autonomous System Behaviour

Dstl research into the representation of Human and Autonomous Systems Behaviour (HASB) in a coherent manner across SSEs has continued to develop from previous research [11,12,13,14], in addition to work conducted by NATO MSG-127 [15], with a particular focus on operational and natural environment effects on human behaviour and autonomous systems.

Dstl commissioned two scoping studies [6, 9] to review and identify areas for further work relevant to the representation of HASB in simulation. The studies found that NATO MSG-127 research described many desirable aspects of a Human Behaviour Model (HBM), such as extensible design, standard compliance, and inclusion of a reference model, although did not attempt to define a realistic HBM. However, the scoping studies reported numerous gaps and challenges associated with representing HASB in simulations, including,

- a lack of consensus on the behavioural factors needed, and a similar lack of an agreed framework for their representation;
- a lack of available behavioural data sets to serve as a basis for building or validating HASB models;
- a lack of relevant technical standards or standards development activities;
- technical and architectural challenges associated with HASB simulation implementation;

As a starting point for developing a unified requirement for the representation of HASB in simulation, these studies have developed draft taxonomies of factors that affect HASB, based on integrating and rationalising factors found across multiple sources [8]. The taxonomies will serve as the basis for developing a common vocabulary and understanding across the disparate communities that need improved HASB simulation.

As part of the scoping studies into HASB in simulation, the work investigated the application of the draft taxonomies for use with a proposed Pattern of Life (PoL) Definition Language (PLDL) [16]. The PLDL is simulation agnostic and defines human behaviour independently of a geographical area with a current focus on representing 'patterns of life' within large-scale urban environments ("megacities"), using a Behaviour

Tree[2] approach. However, in trying to apply wider and more complex representations of behaviours, limitations to the Behaviour Tree method were realised. An extended version of Pattern of Life Definition Language (PLDL X) has been investigated which includes a wider range of behavioural factors and looks at other methods for authoring behaviour, including Utility Theory[3], Steering Behaviours[4] and Emotional State[5] Representation, including a combination of these methods. These provide differing types of decision making, which allows modelling behaviour in detail and more accurately.

2.2 Representation of the Future World

2.2.1 Representation of Weather Effects

Representation of weather effects and climatic conditions within simulation systems has traditionally been poor, mainly due to lack of requirements and limitations in technology. This has resulted in disjointed approaches, which have typically resulted in,

- Two-dimensional representations of clouds for ground training systems, which cannot be re-used for airborne training systems;
- Atmospheric modelling which does not match reality; for example air temperature and pressure may affect a flight model but do not affect cloud formations;
- No link between representation of weather visually and its effect on the environment), systems, equipment and human behaviour;
- Disparities in weather representation within heterogeneous distributed simulation systems where some systems represent weather some do not, and some simulate contradicting weather;

Research has initially prototyped methods for representing coherent weather effects in simulation systems [17], engaging with the UK Meteorological Office for the provision of historical meteorological data. This explored ways of integrating and visualising consistent weather, including the effects of weather on systems and sensors. The UK Meteorological Office has a very extensive archive of Meteorological & Oceanographic (METOC) data, which provides a source of authoritative data to provide correlated representations of the state of the natural environment across SSEs.

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[2] Behaviour Trees are a tree-based representation of hierarchical nodes that control the flow of decision making of an entity.

[3] Utility Theory models behaviours by concurrently analysing many behaviour options and selecting a preferred one based on comparing a score (or 'utility') for each.

[4] Steering Behaviours are based on a mathematical algorithm arising from vector addition, where one or more vectors represent a course of action that can be developed based on one individual factor (e.g. repulsion from an object or attraction to an object).

[5] Emotional State is a behaviour authoring mechanism that allows entities to change and behaviourally 'grow' during a simulation scenario.

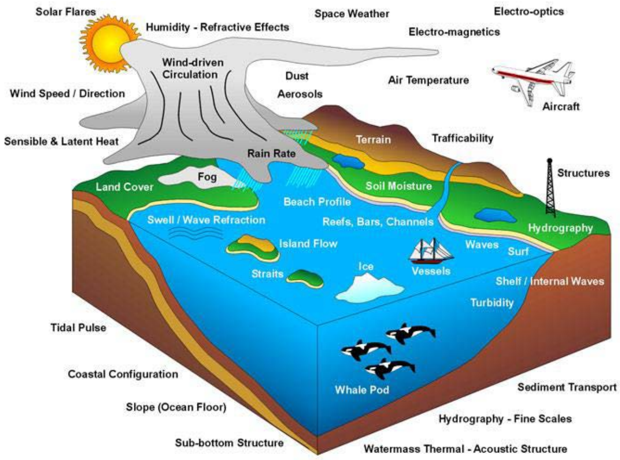

Figure 3: Example of Available Environmental Data

The representation of realistic weather and the effects of weather on operational environments is an important element of the use of SSEs for defence training. In most current simulations where the effects of weather are represented this is mainly static in both time and space, whereas real-world weather can be very dynamic and have significant effects on operational systems (e.g. effects of rain on sensors and ground vehicle mobility, atmospheric effects on unmanned air vehicles). Working in conjunction with coalition partners as part of the NATO MSG-156 Task Group (TG) on "Dynamic Synthetic Environments for Distributed Simulation" current research into methods for the representation of weather in SSEs is addressing,

- Which data sources are suitable to introduce realistic weather in SSEs?
- Methods and technologies to readily specify and integrate consistent weather data and its variations into distributed simulation systems.
- Which weather variations are important and need to be represented in SSEs.
- The representation of weather effects on natural terrain features, military platforms and systems in a consistent manner across SSEs.

2.2.2 Representation of Physical Force Effects

Research has demonstrated an approach to achieving consistent representation of terrain deformation across distributed simulations to represent the effects of a munitions explosion, such as damage to road networks and local infrastructure (see Figure 4). This was based on the use of the Open Geospatial Consortium (OGC) Best Practice of the Common Data Base Specification (CDB).

Figure 4: Deformed Terrain - Munitions Effects

CDB specifies an open format and encoding for the storage, access and modification of a representation of the natural and physical SNE for simulation applications. The CDB defines the data representation, organization and storage structure of a worldwide synthetic representation of the earth. This is assessed as a maturing technology that provides a level of flexibility for maintaining a repository of terrain source data, 3D model data [18].

When run-time modification of a terrain data set is required such as terrain deformation effects, a micro-service approach can be employed where the source data is modified with the modifications reflected through re-refinement of the repository source data. The research demonstrated a process for 'down sampling' terrain source data to reduce the Level of Detail (LoD) from a high resolution data set to LoD required by an end user simulation.

Data exchange between a storage repository and a simulation should use open standards, ideally such as those designed for the transmission of tiled geospatial data sets. Recommended standards are the OGC Web Map Service (WMS) and Web Coverage Service (WCS) interface standards for tiled raster data sets, and the Web Feature Service (WFS) for vector data sets.

The findings from this research are being used to contribute to NATO MSG-156 activities.

2.2.3 Representation of Non-Physical Force Effects

Non-physical force effects are the utilisation of methods that do not require the kinetic force. The development of hybrid warfare tactics that combine both physical and non-physical warfighting is becoming increasingly common, including the use of social media, which allows the analysis of social behaviour and provides readily available intelligence for control, manipulation, and targeting. One element of this is IW, which by its nature can be complex and subtle. Through analysis of previous research [19, 20] this raised the issue of modelling IW and the challenges that make it difficult to simulate. Previous research has investigated how the information domain could be described, which was intended to form the basis for an architecture around which subsequent experimentation could be conducted.

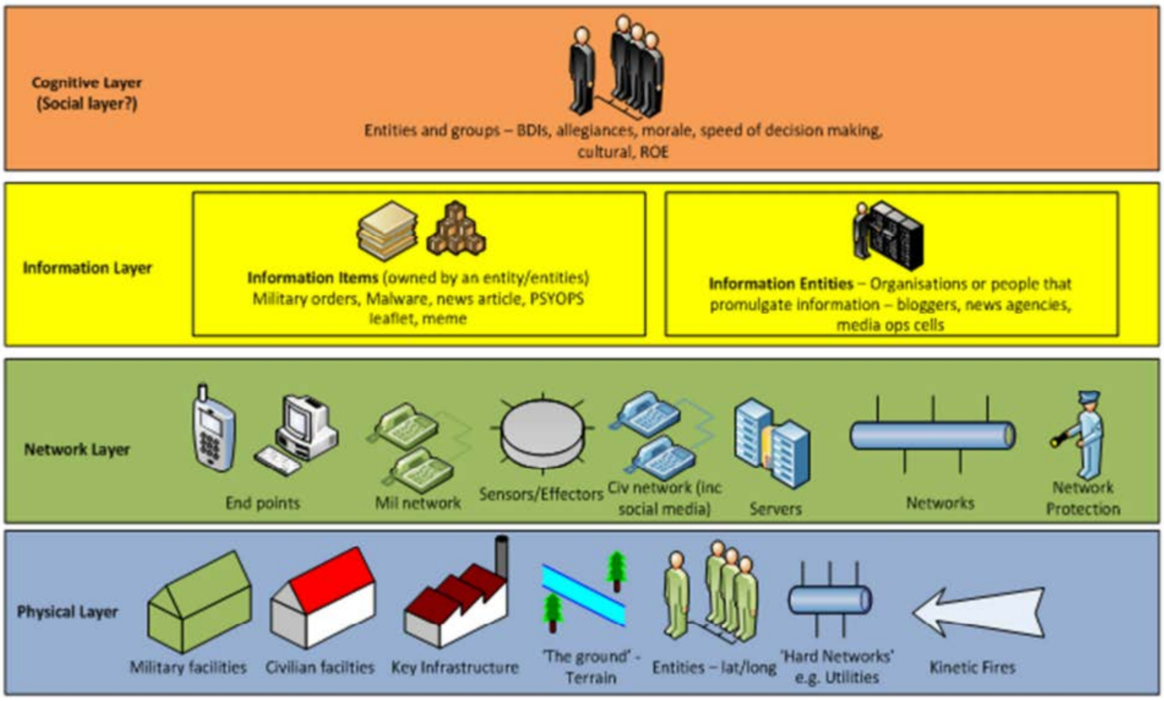

Figure 5: SCORE Development of TTCP JSA 2 KTA 3 Model

Several models were considered for representing the information domain in simulation including NATO Allied Joint Doctrine for Information Operations and The Technical Cooperation Program (TTCP) Joint Studies and Analysis (JSA) 2 Key Technical Area (KTA) 3. The Research Team developed the TTCP model further (see Figure 5) to represent to outline the component elements of each layer so that the information flow between the layers could be better understood. The model includes the following layers,

Physical Layer – Represents the location and state of physical infrastructure represented in the simulation, entities locations, and hardware such as communication towers. It also represents whether an entity has a means of communication in order to send a message i.e. they are next to or are carrying an operational communications device i.e. the battery is not flat. For people speaking to each other without the aid of any communication equipment, the network layer checks that they are physically close so could reasonably be expected to hear each other. In addition, the physical layer is required to represent physical weapon effects, for example is the communication infrastructure still operable after an attack.

Network Layer – Represents the ability to pass information between different network elements. Providing redundancy in the network enables messages to be received even if parts of it are disabled. The network layer will be affected by several effects including,

- destroying elements of the network infrastructure;
- electronic warfare e.g. jamming;
- line of sight e.g. between VHF transmitters/receivers;
- weather e.g. affecting atmospheric propagation of the electro-magnetic spectrum;
- cyber-attacks e.g. denial of service;

For some uses, it may only be necessary to represent the effect of the above on the network rather than having a detailed simulation. As an example, a denial of service attack could be represented by just disabling one of the nodes in a network.

The network layer should also control the propagation of the information on it, for example, representing the delays in receiving messages due to factors such as users not forwarding messages as a result of not immediately reading them or not having their phone with them.

Information Layer - Represents the information that is passed between entities or infrastructure on the physical layer in two forms. Control over the information layer should dictate the ability to change the content of the information, for example, if an aggressor obtains control of a communication system.

- Information Items – This is content that is owned by entities i.e. knowledge. This could take the form of orders, instructions or social media content.
- Information Entities – This organisations or people create or generate information content. Examples of this could include bloggers, news outlets, or military command and control elements.

Cognitive Layer - This layer represents the human element including allegiances, morale, and speed of decision-making. It can also identify groups/communities of users that are able to communicate with each other e.g. Skype address book. It provides the ability of introducing spoofing of users who can create fake news, etc.

3.0 PLANNED / FUTURE ACTIVITIES

3.1 People and Autonomous Systems

Based on outputs from the scoping studies, which includes taxonomies for representing human and autonomous systems behaviour, future work is planned to develop methods and reference architecture for re-usable and composable behaviours in SSEs. The objective is to support a coherent 'plug and play' implementation, and to extend this to support to the behaviour of manned platform and remote controlled/autonomous systems. After an initial phase that will review definitions, roadmap and identify Use Cases, this work will focus on an experimental and exploitation phase, which will explore questions such as:

- Does the taxonomy of human and autonomous systems behaviour provide a foundation for composing behaviour as part of simulation systems?
- What is the future direction for methods and technologies for behaviour representation in simulation?
- What are the timescales for developing a suitable architecture for supporting a composite set of behaviours and their interactions in simulation systems?
- What simulation infrastructure is required? How are we going to test this infrastructure?
- What are the benefits/barriers to maximise wider defence exploitation?

3.2 Future Systems

A scoping study will be carried out to scope the performance, interactions, and effects of new and novel types of operational system capabilities that will need to be considered for representation as part of FOEs in SSEs. The aim of the scoping study is to,

- Investigate and review developments of future platforms (e.g. swarms of autonomous systems), weapons, and sensor technologies and their effects on future operating environments.
- Evaluate how these developments in defence systems will affect future synthetic training.
- Develop a Use Case that can be taken forward to evaluate the representation of future defence systems in simulation.

The findings from the scoping study will be used to inform the direction of future research relevant to providing advice and informing MOD on approaches for the simulation of the operational performance, interactions and effects of new and novel systems, e.g. sensors, weapons, platforms etc.

3.3 Representation of the Future World

Future research into PoL will look at demonstrating an enhanced representation of behaviour including disruptions to 'patterns of life' and infrastructure due a range of physical and non-physical effects. This will cover, but not be limited to, the effect of EW and IW effects such as offensive cyber, fake news and the effect of the destruction of infrastructure. In addition, the research will also investigate second and third order effects, for example the effect of damage to communications/utility networks, and manipulation of social media by hostile actors.

This work aims to demonstrate the ability to simulate the increasing complexities of future operating environments, including 'megacities' and emergent operating domains. Megacities are a complex geographical environment, which consist of congested spaces information networks used to manage smart environments. Furthermore, busy road networks limit the trafficability of land vehicles and tall skyscrapers make air support challenging if not impossible. There are challenges involved in representing such dense environments visually as well as being able to represent the effects on complex infrastructures such as transport and utilities.

Simulating human behaviour within megacities is a challenging problem. Much of the challenge is in addressing variations of scale; the megacity, by definition, must contain many thousands of human entities, but to be truly useful it must simulate each human's behaviour at a high enough level of fidelity to produce realistic and believable patterns. Additional to this challenge is the technical and computational limitation of simulating such large numbers of entities in a high-fidelity virtual environment.

Games Engines[6], such as Unreal Engine 4[7], are looking to provide compatibility with technologies to support the representation of synthetic terrain formats such as the OGC CDB and simulation interoperability standards. Unreal 4's ability to render larger entity counts, import complex urban environment models and deliver advanced physics models, could be utilised in conjunction with previous research and pattern of life to more accurately represent the second and third order effects of physical events in urban environments. The utilisation of games engine technologies will be reviewed as part of the Future World research.

4.0 RESEARCH OUTCOMES

The research outlined above is investigating the development of methods and technologies to provide coherent representation of the future operating environment in simulation for Training and Education (T&E), including the composition of people, institutions and autonomous systems behaviour. This will address a wider spectrum of operational effects and the complexities of these environments to support factors that future decision makers will need to consider in a complex and uncertain future world.

The output from this research aims to benefit UK MOD by informing Policy and Strategy relevant to supporting increased Force Readiness through an improved ability to represent the future operational environment in SSEs in a more timely and agile manner across Defence. The work will also position the external supplier base to develop simulation capabilities relevant to meeting future defence needs.

[6] Games Engines are software development environments created primarily to develop Video Games. The environment provides existing high-end visual graphic rendering and physics and audio capability that provides a platform to develop. This provides significant advantages and greatly reduces development time and cost. Games Engines often provide access to a market place where third party add-ons can be purchased usually at no or relatively low cost which can further reduce development effort.

[7] 'Unreal 4' is a games engine developed by Epic Games, which is predominantly developed for the Games Industry. Training and Simulation, of which a large part is defence, is considered to be one of Epics four market sectors alongside entertainment, architecture and automotive.

5.0 RECOMMENDATIONS

Related to this work there are several opportunities for collaboration with NATO MSG following on from the preliminary research studies including,

- The development and adoption of a common taxonomy and shared vocabulary for simulating HASB;
- recommendations for a future standard covering the utility of a simulation agnostic method for authoring PoL for use in simulation;
- A review of technologies, including gaming engines relevant to rendering larger entity counts, importing complex urban environment models and advanced physics based models for use in simulation;
- Simulation services to represent the FOE (megacities, behaviours, cyber, IW, EW etc.) that can be incorporated into an MSaaS architecture (MSG-164);4

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