Modelling & Simulation as a Service - Empowering Operational Users

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ABSTRACT

The need for modernisation of simulation capability by the United Kingdom Ministry of Defence (UK MOD) is being driven by a number of factors, including the need to:

> Provide a more agile and cost effective approach for rapidly delivering simulation capability to meet the increased and diverse use of simulation across MOD;

> Capitalise on the benefits of technological developments in the IT industry and align with UK MOD ICT (Information & Communication Technology) and NATO strategies e.g. 'cloud first';

> Promote the re-use of simulation resources across the UK Defence Enterprise to reduce acquisition of simulation capability and reduce the through-life costs.

The UK MOD is researching the provision of Modelling and Simulation as a Service (MSaaS) as a potential Enterprise-level strategy to meet these needs and provide recommendations to de-risk the approach.

This paper provides an overview of the UK MOD's research's into implementing an MSaaS capability. It describes the elements of the MSaaS ecosystem and the stakeholders that interact with it. The paper highlights the challenges an Enterprise will face that wants to implement an MSaaS capability and describes issues that need to be resolved if the Enterprise wants to share its simulation resources with other organisations.

Use cases are described to demonstrate how MSaaS can support the needs and provide benefits to different operational users. These include training, mission rehearsal, concept development and experimentation (CD&E), crisis management and data farming. Recommendations are made for a phased approach for delivering an MSaaS capability and the paper identifies where further research is required.

ABOUT THE AUTHOR

Keith Ford has worked in the simulation industry for over 37 years. During this time, he has worked on display systems, control loading, motion systems (for which he obtained his doctorate) and for the last 20 years in the field of synthetic environments.

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INTRODUCTION

Modelling & Simulation as a Service (MSaaS) offers a different approach to providing simulation capability by exploiting Service Oriented Architecture (SOA) and cloud-based infrastructures. The scientific branch of the UK MOD (Dstl) is funding the Architectures, Interoperability & Management of Simulations (AIMS) project to research the concept of providing Modelling & Simulation as a Service (MSaaS). The approach to MSaaS developed by the AIMS team is described in (Ford, Simpson, Stewart, & Mason, 2018) and is briefly summarised in this paper. In order to align the UK approach to MSaaS at an international level, members of the team participated in the NATO Modelling & Simulation Group (MSG-136), which was also investigating the provision of MSaaS (MSG-136, MSG-136 Final Report , 2018). Although the simulation industry has made great strides in developing the MSaaS concept over the last few years, it is still work in progress. This is particularly true with respect to its scope and terminology, which is still evolving.

This paper provides a summary of the potential benefits of MSaaS and then how they are exploited by different Modelling & Simulation (M&S) use cases.

In the context of this paper, the term simulation environment is used to refer to the simulation required to implement an M&S capability. In the most complex case, this might be multiple simulators integrated with operational equipment and supported by common simulations and services installed in multiple clouds.

Motivation for MSaaS Research

The use of simulation pervades all parts of defence including; Training, Mission Rehearsal, Concept Development and Experimentation (CD&E), Crisis Management and Decision Support. Although the benefits of simulation have been readily exploited for training, defence is not fully capitalising on its investment in simulation or exploiting the capability to its full potential due to its fragmented use across the Defence Enterprise.

One of the problems in large organisations is that there is not a central record of all the simulation resources it owns. This can lead to parts of the organisation buying capability similar to what it already owns, which is very wasteful. A key tenet of MSaaS is to have an effective 'discovery' capability to enable simulation resources to be identified and reused.

Recent advances from the Information and Communication Technology (ICT) industry such as cloud technologies can provide many advantages to the way simulations are delivered. These include the use of virtualisation and containerisation, which provide a consistent and agile way of executing simulations on generic hardware. The introduction of SOAs has provided a way of delivering software capability at an Enterprise level via loosely coupled re-usable services. The aim of MSaaS is to capitalise on these developments so as to provide more flexible, cost effective and accessible simulation systems.

MSaaS Definition

There is no universally accepted definition for MSaaS and different people and organisations have a different interpretation of what is meant by the term. However, it is generally accepted that MSaaS is more than just running simulations in the cloud using virtualisation and container technologies. The AIMS definition of MSaaS is (Ford, Simpson, Stewart, & Mason, 2018):

An Enterprise-level architecture that promotes modularity, loose coupling, agility and reusability of Modelling & Simulation resources from different suppliers by making them available on-demand to a large number of disparate users in order to reduce the cost and time for implementing Modelling & Simulation capability to improve operational effectiveness.

A more complete understanding of MSaaS is obtained by decomposing the AIMS definition into the four MSaaS principles:

An on-demand fully transparent and integrated method of moving from an operational requirement to an executable simulation that can deliver that requirement;

A semi-automated composition of simulations re-using existing capability where possible and integrating new if required;

Deployment and execution of simulations decoupled from specific hardware and infrastructure to enable flexible and scalable use;

Sharing of acquired capability, including hardware, software, services and infrastructure.

Figure 1. MSaaS Ecosystem

Figure 1 shows the AIMS MSaaS ecosystem and the stakeholders that use it. The ecosystem comprises;

Simulation Resources: comprises M&S Assets, M&S Services and M&S Blueprints[1];

Registry: a structured, searchable database containing information about M&S Resources (analogous to an electronic, searchable catalogue);

Repository: a store for reusable resources such as M&S Services and M&S Blueprints;

Process: defines how services are Discovered, Composed, Deployed and Executed[2];

Infrastructure: comprises the computing and network elements for executing the Simulation Environment;

Portal & Tools: the Portal provides a single point of entry for accessing the toolset that supports the MSaaS process.

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[1] An M&S Blueprint captures all the information about a simulation including requirements, design and deployment.
[2] NATO MSG-136 has produced an MSaaS overlay for the IEEE Distributed Simulation Engineering & Execution Process (MSG-136, MSaaS Vol.3 Reference Engineering Process, 2018)

The long-term vision for MSaaS is to be able to go from a requirement for producing a simulation capability to delivering the capability with minimal human involvement.

MSaaS BENEFITS

The potential benefits of MSaaS are described in (Doyle, Ford, & Skinner, May 2018) and summarised here.

Reuse of M&S resources: MSaaS encourages a culture of 'buy/develop once, use many times'. This is facilitated by having a registry that provides an effective discovery capability. Even if an M&S resource doesn't exactly meet a user's needs, it is much quicker to modify something than start from scratch.

Reduces cost of providing M&S capability: The reuse of M&S resources can enable significant cost savings. MSaaS promotes the sharing of M&S resources and it is often more cost effective to licence a missing M&S capability from a competitor/supplier rather than developing it in-house. Also, the MSaaS concept promotes the use of automation, which reduces the time (hence cost) for developing and deploying M&S capability.

Deliver M&S capability whenever/wherever needed: A key aspect of MSaaS is that M&S capability can be provided remotely across an appropriate network with access via web services. This enables the MSaaS tools to be always available 24/7 from anywhere in the world.

Enables rapid adaptation to changing needs: Often the requirements for an M&S capability changes throughout its lifecycle. This is particularly true when maintaining the currency of simulation systems when operational platforms and systems are updated. Also, simulation systems need to be flexible to represent changes in the operating environment due to emerging threats or different geographical regions. The ability for MSaaS to identify and access additional M&S capability from a registry/repository along with an efficient composition process facilitates these operational changes. However, the ability to capitalise on the benefits provided by MSaaS may not be realised if the existing simulation capability is constrained by existing commercial frameworks, which make it expensive to make any modifications.

Reduces technical skills required for deploying simulation environments: By reusing previously generated simulation environments, these can be discovered and deployed by non-technical users. Also, the MSaaS ecosystem provides the framework for providing the long-term vision for MSaaS to automatically produce simulation environments from operational requirements with minimal human involvement, which will further reduce the skills required.

Provides efficient use of hardware: MSaaS capitalises on the benefits of recent software developments such as the use of virtual machines, containers and web services, which enables the execution of simulations to be decoupled from specific hardware and infrastructure. The use of more portable software means that dedicated hardware is not required for running M&S capability. This means that the software can be executed on generic hardware such as provided by cloud environments. As the software only has to be loaded when the simulation environment is to be run, less computing hardware is required by an organisation (though the comparative costs of executing on traditional hardware versus cloud hardware has not been fully analysed).

Enables multiple simulations to be run simultaneously: An important feature of MSaaS is its ability to capture the design and deployment of a simulation environment in code that can be run on generic hardware. This means that providing there are sufficient software licences and appropriate man machine interface devices available locally to the user e.g. joysticks, the same simulation environment can be instantiated many times.

Provides resilience by enabling services to be mirrored in a different cloud: MSaaS's use of generic hardware and its ability to run multiple instances of a simulation environment simultaneously means that a parallel simulation environment can be run that can be switched in if the primary cloud becomes unavailable. However, more research is required to determine how to keep the two simulation environments synchronised.

Potential for different business models: MSaaS opens up the possibility of having different business models such as 'Pay As You Go' or the use of credits. As well as paying 3rd parties, in large organisations this may also be applicable to paying for the capability internally to another part of the business. MSaaS also enables SMEs (Small/Medium Enterprises) to provide smaller reusable M&S capability, which will increase competition.

Delivery of an MSaaS Capability

Often M&S activities are distributed across an Enterprise and one of the advantages of providing an MSaaS capability is that M&S expertise and resources are coordinated across the organisation. Different parts of the organisation are not aware of what M&S capability already exists, which can result in different solutions being implemented for a common problem. This is obviously wasteful in terms of time and money. An M&S capability can be provided either by a centralised group providing a 'centre-of-excellence' or virtually using an online information system to pool and share expertise. In either case, an MSaaS ecosystem administrator is required to ensure the capability is available 24/7 and for performing management and maintenance activities. Their most important function is to confirm that information about M&S resources to be added to the ecosystem is compliant with the required metadata standards and accurately reflects the functionality being offered by the Resource Provider. They also need to verify that the M&S Resource performs as described.

In order to promote a culture of reuse, it must be easy to 'discover' new simulation resources. It is important to make the distinction between discovering and searching for M&S Resources. Discovering an M&S resources relates to finding something that you didn't previously know about whereas you 'search' for something you know about but don't know where to find it. The digital age has completely transformed the way we purchase goods. Rather than going down to the local shops, our first port of call these days is the Internet. Even non-millennials expect to be able to browse the web until they 'discover' exactly what they want. Therefore, the ability to reuse M&S resources must be as simple in order to meet people's expectations; hence acceptance. The use of the registry should not be limited to just M&S resources but should also contain information about where/how to access operational equipment that may be required for collective training or mission rehearsal (see next section) and details of subject matter experts.

When a large number of M&S resources have to be managed, the AIMS research recommends the use of a registry with well-structured metadata to enable M&S resources to be discovered. The metadata would point to repositories managed by the Resource Providers that enable the latest version of the resource (or previous versions if required) to be downloaded. This allows the Resource Providers to control access to their intellectual property and ensures any bug fixes are always promulgated. In order to exploit the service oriented approach for delivering simulation capability, the registry must be searchable by computers as well as humans. This is because the MSaaS concept developed by AIMS automates the deployment of simulations onto the infrastructure.

The real benefits of MSaaS as described above can only be achieved if an Enterprise is completely committed to the concept. This will require a high-level champion in the organisation to mandate that this is the way simulation capability will be delivered as a change in culture is required, which is supported by an organisational wide simulation strategy and policy. Also, there will be a cost associated with implementing the MSaaS ecosystem and this investment will only be recouped if the organisation is committed for the long term. However, the delivery of an MSaaS capability can be implemented in phases, so MSaaS can be viewed as an evolution rather than a revolution. The current AIMS research has identified that there are quick-wins that can be implemented now, such as the automatic deployment of simulation environments on cloud based infrastructures; medium-term capability, such as the implementation of a registry based discovery system and longer-term such as automating the MSaaS process.

MSaaS USE CASES
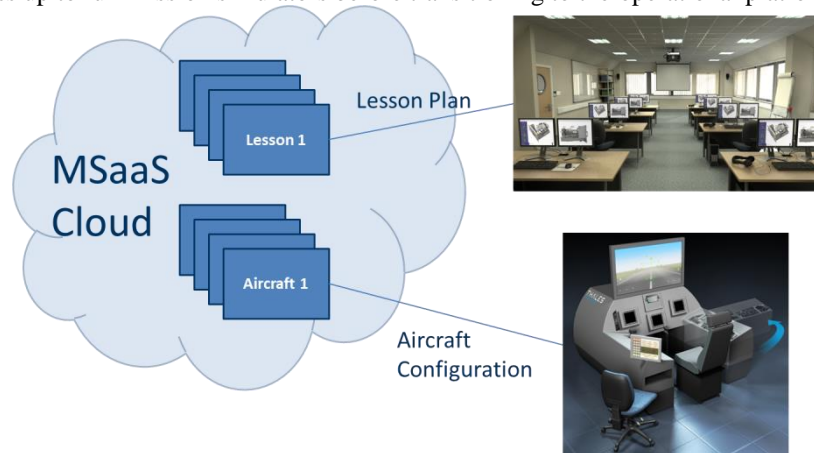
This section describes how MSaaS can be applied to different uses of M&S and the relevant MSaaS benefits associated with them.

Training Use Case

Training provides one of the most common uses of simulation and is pervasive in many different industries. Traditionally training is performed in bespoke standalone simulators under the supervision of a qualified instructor. The instructors are authorised to provide training on a limited number of training devices and become very familiar with the idiosyncrasies of the simulators. The life span of a full mission simulator can be several decades and updates are performed throughout its life-cycle to align the performance with the specific platform being simulated. Also, enhancements may be required to the simulator's capability to improve its usability or if new geographical areas or threats need to be represented. Although simulators are often used standalone, there is a move to collective training, which requires simulators to be networked and to operate in a common battle space.

Software used on the actual platforms is often re-hosted on the simulator to ensure maximum fidelity. However, to reduce the cost of training, a range of devices with different fidelity may be provided ranging from computer based
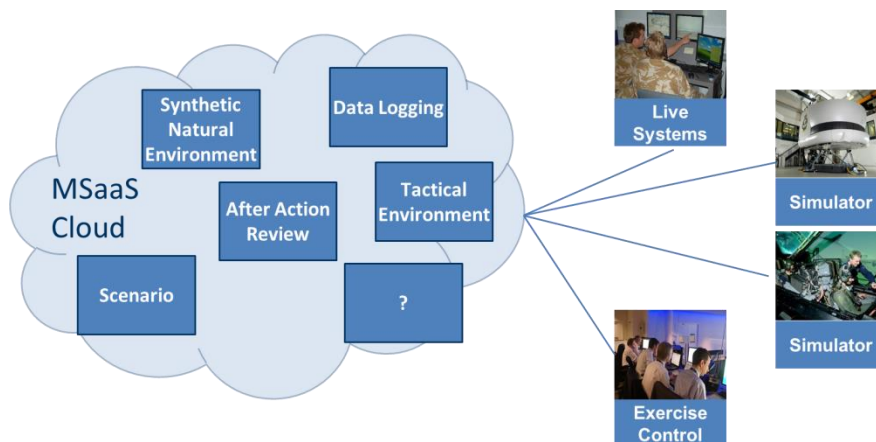
training (CBT), flight training devices (FTD) to full mission simulators (FMS). Trainees start learning on lower fidelity devices and progress up to full mission simulators before transitioning to the operational platform.

Figure 2. MSaaS applied to CBT and FTD

Computer based training is often performed on generic hardware which is compatible with MSaaS's use of cloud based infrastructures. This means that if the training has been designed to be web based, it can be downloaded from an MSaaS repository and installed on a cloud when and where required (Figure 2). An advantage of this is that it enables a much more efficient use of hardware as users are only paying for the computing facilities when they are being used. For civil airline pilots, it means that they can search for and perform refresher training courses in hotel rooms during stop-overs. In a military context, it means that individual training can be performed in barracks without the costs associated with travelling to and staying near a training facility.

For reconfigurable FTDs, MSaaS provides the ability to download software from an MSaaS repository and to configure the device to a particular platform (Figure 2). In addition, MSaaS provides the ability to capture lessons learnt and best practice, which can improve the efficiency of the training.

Figure 3. MSaaS Applied to Collective Training

Collective training often requires the production of a complex system that integrates simulators, operational systems and support functions e.g. data logging (Figure 3). MSaaS facilitates collective training by enabling suitable systems to be identified from the registry and having designed and stored the blueprint of the system in a repository, for it to be rerun on demand (with the common functions potentially running in a cloud environment). It also facilitates the

ability to provide a common tactical and physical environment, which is essential to ensure a 'fair-fight'[3]. The benefits of applying MSaaS to training environments that exploit the use of simulation are summarised in Table 1.

Table 1. MSaaS benefits related to training

MSaaS Benefit	Relevance to Training
Reuse of verified M&S resources	Important for example when a visual/CGF database is required by a simulator for a new geographical area or for rapidly producing a collective training system using existing capability, which integrates simulators, real equipment and support functions e.g. data logging, exercise control.
Reduces cost of providing M&S capability	Cost reductions achieved by reusing M&S capability, reduction in travel and subsistence by delivering training at the point of need e.g. in barracks and potential 'Pay-as-you-Go' business models i.e. only pay when training is being performed.
Deliver M&S capability whenever/wherever needed	This enables a trainee to take some control of when they want to do the training. In a military context, delivering training at the point of need can reduce 'night out of beds', which is a current issue.
Enables rapid adaptation to changing needs	Not so important if properly planned as training requirements are normally identified by performing a Training Needs Analysis (TNA) when a new platform is being procured or new capability being introduced and if performed correctly should not change. Similarly there is not usually a time issue if changes are made to the platform and a simulation upgrade is required.
Reduces technical skills required for deploying simulation environments	Enables previously designed complex distributed training systems to be deployed by operational personnel, which makes them more accessible.
Provides efficient use of hardware	Some training functionality can be delivered on generic hardware that only needs to be employed whilst training is being delivered. This can reduce capital costs.
Enables multiple simulations to be run simultaneously	Important when say pre-deployment training has to be performed by units before conducting a joint exercise. Units can perform training when it suits them rather than having to schedule it.
Provides resilience by enabling services to be mirrored in a different cloud	Important for large training exercises that involve thousands of people and takes years to plan as loss of the simulation capability stimulating the exercise will disrupt training. This can be very costly, may mean the training opportunity is lost and the use of simulation loses credibility with operational personnel.
Potential for different business models	Can provide potential cost savings if training can be procured in a more cost effective way.

Mission Rehearsal

To maximise the success of a military mission, all aspects of the operation are rehearsed prior to conducting it to ensure that all known eventualities are explored and that there are no surprises. Mission rehearsal is typically performed on existing full mission simulators. These can be used stand-alone or networked together. Even when a simulator is used in isolation, MSaaS aids mission rehearsal as the reuse of M&S resources may enable the simulator to be quickly upgraded so that it can support new requirements. Currently it can take a significant time to create databases for visual and Computer Generated Forces (CGF) systems for a new area and it may be possible to reuse ones that already exist. However, for mission rehearsal, simulators may be networked and integrated with other capability as in the collective training example shown in Figure 3; for example an F35 simulator may be integrated with a JTAC[4] simulator. For high-tempo operations, there may be little time between discovering a target and conducting the mission. Therefore, the main requirement for mission rehearsal is to be able to rapidly compose the simulation environment in order to maximise the time available for rehearsing the mission. The MSaaS philosophy for reusing M&S resources means that there may be a simulation environment that already meets the requirement or

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[3] Two or more simulations may be considered to be in a fair fight when differences in the simulations' performance characteristics have significantly less effect on the outcome of the conflict than actions taken by the simulation participants

[4] Joint Terminal Attack Controllers direct the action of combat aircraft engaged in close air support and other offensive air operations from a forward position.

more likely one that can be modified. In either case, this could significantly reduce the time required to generate the required capability. Also, the AIMS research has laid down the foundation for automating some of the MSaaS process, which could potentially make time savings (Ford, Simpson, Stewart, & Mason, 2018).
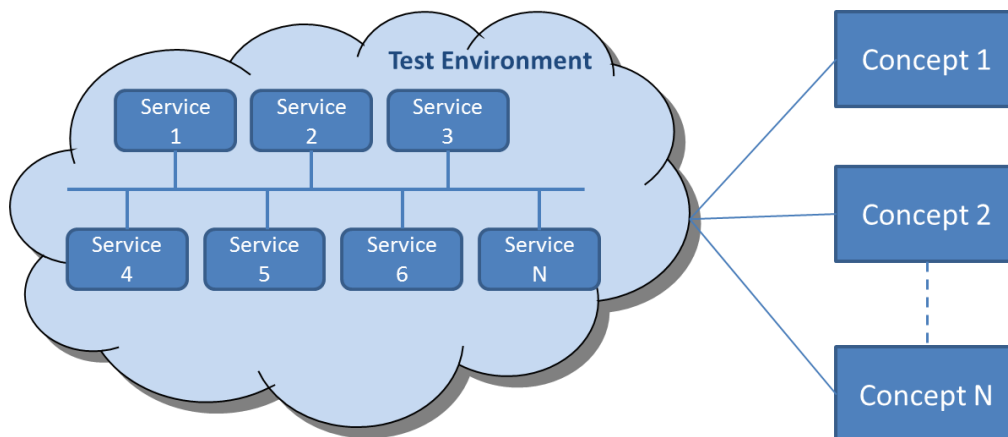
Although the verification and validation (V&V) is crucial to all use of M&S, it is probably most important when it comes to mission rehearsal as if the simulation environment doesn't function correctly e.g. if a Surface-to-Air (SAM) site was incorrectly located, the consequences could impact the success of the mission and prove fatal. Table 2 summarises the benefits of MSaaS when applied to Mission Rehearsal.

Table 2. MSaaS benefits related to mission rehearsal

MSaaS Benefit	Relevance to Mission Rehearsal
Reuse of verified M&S resources	As time is of the essence for Mission Rehearsal, it is essential to have access to a wide range of M&S resources that can be rapidly discovered and composed in order to generate the required capability rather than it being developed from scratch.
Reduces cost of providing M&S capability	Speed and M&S capability is more important than cost.
Deliver M&S capability whenever/wherever needed	Could be significant if mission is to be rehearsed in theatre or on route to theatre of operations.
Enables rapid adaptation to changing needs	May be important if new intelligence is received that requires additional platforms or systems to be included in the simulation.
Reduces technical skills required for deploying simulation environments	Not so important as every effort will be made to ensure the relevant skills are made available to ensure the M&S capability is delivered in the most efficient manner.
Provides efficient use of hardware	Not important.
Enables multiple simulations to be run simultaneously	May be important if parallel missions are conducted in order to perform 'what-ifs'.
Provides resilience by enabling services to be mirrored in a different cloud	Resilience is important to ensure that the mission can be conducted without interruptions but it must be possible to deliver this capability without adding significant time in generating the simulation environment.
Potential for different business models	Not relevant as being able to rehearse the mission is more important than cost.

Concept Development and Experimentation (CD&E)

The main requirement for CD&E is the ability to have access to a wide range of simulations and services that can easily be composed to produce a simulation environment, which can be used to explore new concepts. Due to the operational and financial implications of the decisions being made, particular care is needed to ensure that the M&S is fit for purpose for the CD&E activity being performed. Therefore, there is a high scrutiny on the Verification and Validation (V&V) of the resulting simulation capability.

Figure 4. CD&E Simulation Environment

MSaaS supports CD&E by providing a catalogue of M&S resources from which a Simulation Developer can select simulations and services to represent the capability. This can be used by potential users to evaluate the concept and provide feedback before any money is committed. Initially any existing low fidelity simulations may be used to perform the investigation but as concepts are further developed, MSaaS enables the lower fidelity simulations to be swapped out for higher fidelity ones. A test environment can be produced to stimulate the inputs of a new concept (Figure 4) and MSaaS's ability to easily swap simulation functions can be used for comparing solutions from different suppliers. As MSaaS supports the ability for simulations to be distributed, Original Equipment Manufacturers (OEM) can run their solutions at their own site so they can maintain control of their intellectual property.

The successful outcome of CD&E will lead into a full simulation based acquisition (SBA) lifecycle. In this case, the simulations developed for investigating concepts can be exploited in later phases of the programme such as for providing a Systems Integration Laboratory (SIL) and for developing a simulator to train operators of the equipment. The ability of MSaaS to catalogue and store the intermediate simulation products ensures that they are reusable throughout the lifecycle of the programme.

An example of the use of simulation in CD&E is the UK's Watchkeeper UAV programme where existing simulation resources were modified to represent a Watchkeeper system, The configuration of an existing flight model was altered so that it flew like the UAV; an existing database was used to generate the output from the electro-optic and infra-red sensors, and the software for a flight simulator's instructor operator station (IOS) was modified so that it provided the controls of a simple ground control station. The ability to demonstrate the Watchkeeper concept at the start of the programme and to show how the simulation could be used to develop the Concept of Operations (CONOPS) greatly increased the customer engagement compared to traditional PowerPoint presentations. It also enabled operational users to provide feedback at an early stage of the products development.

The benefits of applying MSaaS to CD&E are summarised in Table 3.

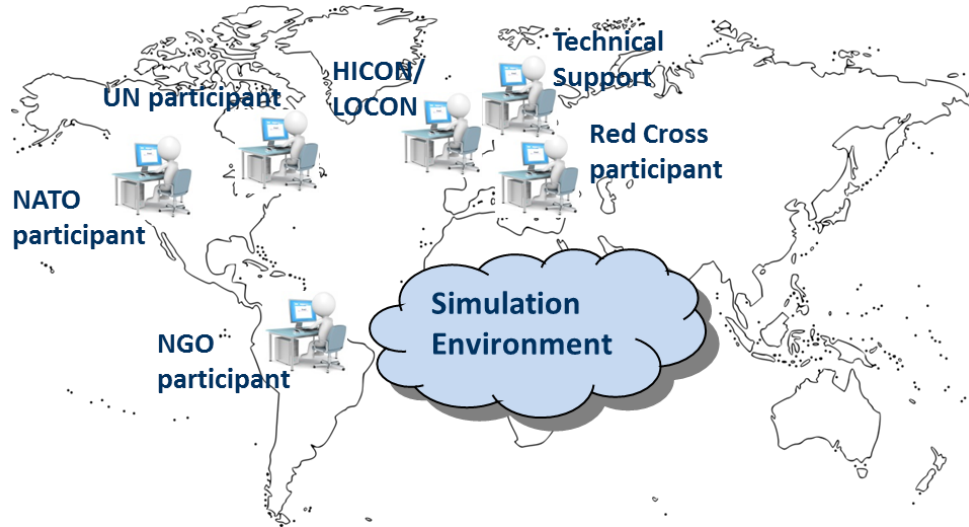**Table 3. MSaaS benefits related to CD&E**

MSaaS Benefit	Relevance to CD&E
Reuse of verified M&S resources	Essential to have access to a wide range of M&S resources that can be rapidly discovered and composed in order to generate the required capability rather than it being developed from scratch.
Reduces cost of providing M&S capability	Lowering the cost of producing a more comprehensive simulation environment may facilitate a more extensive evaluation of the concept.
Deliver M&S capability whenever/wherever needed	Important where solutions are executed at an OEM and integrated into a remote test harness.
Enables rapid adaptation to changing needs	Important as new M&S requirements emerge as concepts evolve and higher-level fidelity models are required.
Reduces technical skills required for deploying simulation environments	Not so important as people developing and investigating concepts will be technically minded.
Provides efficient use of hardware	Use of generic hardware enables complexity of simulation environment to be scaled-up as the solution evolves.
Enables multiple simulations to be run simultaneously	Enables solutions from different manufacturers to be developed and investigated simultaneously.
Provides resilience by enabling services to be mirrored in a different cloud	Not so important for CD&E unless demonstrating concept to high-profile stakeholders.
Potential for different business models	Not important.

Crisis Management

Crisis management exercises such as performed by the Swedish Armed Forces (Viking 18, 2018) typically require complex simulation environments to support the many organisations/agencies involved e.g. military, police, Red Cross, etc. The number of participants can be in the hundreds or thousands. Real equipment is stimulated by the simulation so that participants are able to operate the systems they would normally use in the event of a crisis. The

integration of the simulation environment with disparate operational systems will be very challenging as they are likely to be distributed across many sites.

MSaaS benefits crises management exercises as the reuse of M&S resources speeds-up the development of the simulation environment. To promote greater reuse, AIMS has introduced the concept of sub-compositions, which are groups of services that perform a particular function. As an example, a crisis management exercise may make use of a pattern-of-life (POL) sub-composition to improve the realism of the exercise by representing realistic numbers of people and vehicles. Other sub-compositions may provide visualisation, exercise control tools and live data feeds. Once a simulation environment has been designed, it can be stored in the registry/repository and easily deployed to the infrastructure if the exercise is to be rerun.
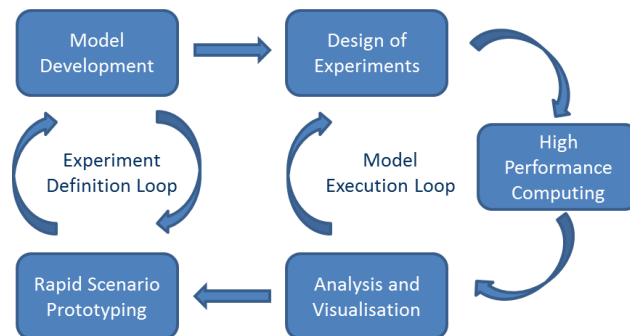

Figure 5. Example Crisis Management Exercise

A feature of crisis management exercises is the large number of higher-control (HICON) and lower-control (LOCON) players that feed information to the training audience (Figure 5). As well as storing the different software components for the simulation environment, the registry can also contain information about suitably qualified & experienced personnel (SQEP) who may be able to support the exercise. Table 4 summarises the benefits of MSaaS when applied to crisis management.

Table 4. MSaaS benefits related to crisis management

MSaaS Benefit	Relevance to Crisis Management
Reuse of verified M&S resources	Facilitates the development of a suitable simulation environment from existing M&S resources, which speeds-up its development.
Reduces cost of providing M&S capability	By reusing M&S resources and reducing the time to create simulation environment.
Deliver M&S capability whenever/wherever needed	Crises management exercises are normally distributed and the simulation capability can be delivered to where the agencies are based.
Enables rapid adaptation to changing needs	Not so important for crises management as changing requirements would only be incorporated during planning and development.
Reduces technical skills required for deploying simulation environments	There is always a desire to reduce the number of technical staff in large exercises; however, this must not compromise the successful execution of the exercise.
Provides efficient use of hardware	Ability for simulation environment to be deployed on generic hardware is important so that it can be uploaded anytime the exercise has to be rerun.
Enables multiple simulations to be run simultaneously	Applicable when there is a desire to practice multiple crisis management exercises simultaneously or performing 'What-if' analysis.
Provides resilience by enabling services to be mirrored in a different cloud	Due to the large number of people involved in crisis management exercises who would be affected if something was to go wrong, resilience should be designed into the simulation environment.
Potential for different business models	Not so important to crisis management.

Data Farming

Data Farming is the process of using simulation to perform experiments to 'grow' data, which can then be analysed using statistical and visualisation techniques to obtain insight into complex systems (Data Farming, 2018). The knowledge and information generated by data farming can be used in-house or sold to third parties.

Figure 6. NATO MSG-155 Data Farming Process

Figure 6, which is adapted from the work conducted by NATO Task Group MSG-088 (Horne & Schwierz, 2016) shows that data farming is an iterative team process comprising a set of embedded loops. Simulations are developed to conduct experiments, which are run on generic hardware. Support functions are provided for scheduling, initialising, and launching the simulation, and for analysing and visualising the results.

MSaaS can support data farming by providing a catalogue of suitable simulations and services that may be rapidly composed. Having defined an experiment, MSaaS enables it to be deployed on the infrastructure multiple times, which facilitates Monte Carlo simulation. It should be noted that the type of simulations required for data farming are likely to be incompatible to those used for the other use cases as they will generally have to be run faster-than-real-time. Once the data for an experiment has been analysed, it can be stored along with the simulation environment and with any reports. The benefits of applying MSaaS to Data Farming are summarised in Table 5.

Table 5. MSaaS benefits related to data farming

MSaaS Benefit	Relevance to Data Farming
Reuse of verified M&S resources	Facilitates the composition of a suitable experiment from a library of existing M&S resources.
Reduces cost of providing M&S capability	Makes use of data farming techniques more viable.
Deliver M&S capability whenever/wherever needed	Not important.
Enables rapid adaptation to changing needs	Important as new understandings emerge, which require another iteration of the model execution loop.
Reduces technical skills required for deploying simulation environments	The desire is for MSaaS to provide a composition capability whereby analysts could generate experiments by 'dragging and dropping' components from a library.
Provides efficient use of hardware	Important when many experiments are performed in parallel.
Enables multiple simulations to be run simultaneously	Important to be able to reduce the time to generate data by running experiments in parallel.
Provides resilience by enabling services to be mirrored in a different cloud	Not important.
Potential for different business models	Not important.

CONCLUSIONS

MSaaS provides many advantages to the way M&S capability is delivered and this paper describes the benefits to five different use cases, which are summarised in Table 6. The analysis shows that the main benefit of MSaaS is it facilitates the reuse of simulation resources as this can save both the development time and cost of producing a simulation environment.

Table 6. Summary of MSaaS benefits for different use cases

MSaaS Benefit	Training	Mission Rehearsal	CD&E	Crisis Mgt	Data Farming
Reuse of M&S resources	✓	✓	✓	✓	✓
Reduces cost of providing M&S capability	✓		✓	✓	✓
Deliver M&S capability whenever/wherever needed	✓	✓	✓	✓	
Enables rapid adaptation to changing needs		✓	✓		✓
Reduces technical skills required for deploying simulation environments	✓				
Provides efficient use of hardware	✓		✓	✓	✓
Enables multiple simulations to be run simultaneously	✓	✓	✓		✓
Provides resilience by enabling services to be mirrored in a different cloud	✓			✓	
Potential for different business models	✓				

MSaaS has been identified as an important enabler for delivering NATO's M&S strategy and industry is beginning to realise that it can disrupt the way simulation capability is currently delivered. The AIMS research has demonstrated a successful discovery capability and has produced prototype tools for composing and deploying simulation environments comprising simulators, virtual machines and Docker containers to cloud based infrastructures. However, as the capability has only been demonstrated in a lab environment, the overall Technology Readiness Level (TRL) of the AIMS MSaaS implementation is currently at TRL 4.

More research is required particularly in the areas of discovery and composition. The implementation of a comprehensive discovery capability requires further development of the registry information model, which defines the relationship between the different registry objects. Also, the current research has only defined metadata for a limited number of simulation resources and this needs to be extended to the full gamut of simulation resources that can be made available for reuse. The desire to share simulation resources at an international level with coalition partners will require the development of new standards (Skinner & Siegfried, MSaaS Standards - Finding our assets, 2018).

The integration of simulation capability and how it is deployed out to the hardware is still challenging and requires significant engineering effort. However, once a simulation environment has been designed, AIMS has shown that it can be re-deployed without requiring any technical skills. The issue of security has to be addressed whether for both military and civil use, as most implementations of the MSaaS ecosystem are expected to be distributed making them vulnerable to cyber-attack. Security has been identified as an important topic in the NATO MSG-164 group, which is further developing the MSaaS concept. NATO MSG-164 runs from 2018 – 2021 and its members will continue to

evaluate the benefits and challenges of implementing MSaaS. In addition to developing the technology for implementing an MSaaS solution, MSG-164 is also investigating the business and governance issues. The aim is to develop an evidence base that can be used to help inform decisions regarding the introduction of MSaaS in an Enterprise.

The introduction of MSaaS to an organisation will not be without its problems, and some of these are identified in (Skinner, Lloyd, Ford, & Cox, October 2018). It is recommended that MSaaS is implemented in phases with the experience gained from using the capability in early phases informing subsequent phases. A deployment capability should be implemented first as this is the most mature of the MSaaS functions. This should be followed by a discovery then a composition capability.

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