Towards a Synthetic Environment Ecosystem for Test & Evaluation

Robert Siegfried
Aditerna GmbH
Otto-Hahn-Str. 13 B
85521 Riemerling
GERMANY

robert.siegfried@aditerna.de

Robert Marshall
Maranis Ltd
131 Bay Tree Road
Bath, BA1 6NG
ENGLAND

robert.marshall@maranis.co.uk

Alessandro Faraci
QinetiQ Training & Simulation
Ltd, Cody Technology Park, Old
Ively Road, Farnborough, Hants,
GU14 0LX, ENGLAND

alessandro.faraci@t-s.qinetiq.com

ABSTRACT

As part of the future UK defence requirement for Test and Evaluation (T&E), Federated Synthetic Environments (FSEs) will be used to a greater extent. The Defence Science and Technology Laboratory (Dstl) envisions that this may be achieved through the creation of a Synthetic Environment (SE) ecosystem for T&E that is effective, promotes coherency and consistency, is readily sharable and reduces duplication of work.

The aim is to provide multi-fidelity, multi-layered SEs that bring together the capabilities (layers) needed for a certain task at the required fidelity. Also, users must be enabled to conduct T&E in new ways or on emerging systems, such as increased use of digital twins, or T&E on Artificial Intelligence systems.

A broad industry team was tasked by Dstl to investigate this conceptual approach, a whole ecosystem of products, services and processes. This includes content produced by multiple suppliers, with novel arrangements to facilitate re-use, catalogues for accessing content, tooling to compose this content into FSEs, runtimes, deployment and hosting services, and analytical tools. Another key element is the ability to easily include content from multiple sources, including international partners. Beyond technical considerations, this requires proper governance and protection of intellectual property rights. Hence alignment with NATO standards and related NATO efforts, such as establishing a Modelling & Simulation (M&S) as a Service Ecosystem, is critical.

This paper summarizes the investigation's preliminary output covering: needs for such a SE ecosystem for T&E; information on relevant approaches and technologies and; outlines an architecture for a future SE ecosystem for T&E. Relations to NATO efforts are investigated and options discussed how the individual efforts could be aligned to avoid redundant effort and to benefit the envisioned ecosystems.

1.0 INTRODUCTION

As part of the future UK defence requirement for Test and Evaluation (T&E), the Defence Science and Technology Laboratory (Dstl) wishes to encourage both the Ministry of Defence (MOD) and wider industry to implement the use of Federated Synthetic Environments (FSEs) to a greater extent. Dstl envisions that this will be achieved through the creation of a Synthetic Environment (SE) ecosystem for T&E that is effective, promotes coherency and consistency, is readily sharable and reduces duplication of work. Dstl foresees that such an ecosystem will also need to be easily accessible by MOD and its partners to ensure that it is fully used.

In an initial research phase, a study team composed of 12 companies reviewed current MOD policy and strategy documents to understand the future context and aspirations for T&E to set the scene for a future SE ecosystem. Such documents included the Integrated Operating Concept [1], the Defence Capability Framework (DCF) [2], the Digital Strategy for Defence [3], and the Cloud Strategic Roadmap for Defence

[4].

Of direct relevance to T&E is the DCF, which outlines guiding principles that will inform MOD's approach to investment decisions and military capability development over the next decade. As well as listing the capabilities that will come into service over the next 10+ years it devotes a whole chapter to T&E and states that "a step-change in our approach to test and evaluation is required" and whilst "acknowledging the value of UK live trial capabilities, we need to embrace a more digitally enabled future". [2]

The envisioned SE ecosystem for T&E is best described at two different levels:

1. Future T&E will require FSEs with capabilities that were not possible (or available) before. For example, FSEs able to test complex combinations of systems and environments, or to test systems in a greater range of environments, or at a greater level of fidelity, than was previously possible.
2. Rather than developing a small number of rigid, widely used FSEs, future T&E will need a new approach for generating, deploying and using multiple FSEs to test and evaluate against emerging requirements.

Such an SE ecosystem must at the same time be ready to meet the challenges foreseen by MOD both in terms of the demand (what future military capabilities will require T&E) and the supply (how can T&E be more cost effective in general).

2.0 SYNTHETIC ENVIRONMENT ECOSYSTEM FOR T&E

2.1 Synthetic Environments

Synthetic Environments are computer-generated simulations of real or imagined physical environments that can be used for training, research, or analysis. They can be used throughout the development process to test and evaluate new concepts, force structures, capabilities, equipment, weapons systems, tactics and operational plans, to educate defence personnel, train them in the use of new equipment and in the execution of various tactics, and help them rehearse before operations. They provide a safe and controlled environment to test systems and equipment, and to identify potential weaknesses in existing systems, without the need for costly and dangerous real-world testing. They can also be used to simulate different types of weather conditions, terrain, and environments, and to analyse the performance of different systems and equipment.

Within a defence context, SEs are already widely adopted across the spectrum of applications described above. In particular, substantial investments have been made in the development and adoption of SEs in the delivery of training, supporting the full spectrum of training from individual level competencies all the way up to complex team and command level events. In addition, a number of established mechanisms exist that allow disparate simulations to be integrated to build a far richer and more complex training environment.

Although the value of using of SEs for T&E is well-known, it seems that the most attention within Defence is paid to using SEs for training and exercise purposes. This is also underlined by the fact that the majority of existing standards in this domain, such as High-Level Architecture (HLA) or Distributed Interactive Simulation (DIS), are driven by the training and exercise community, and are not necessarily suitable for T&E applications. A potential explanation for this situation might be the huge variety of systems to be tested and evaluated, and the associated intellectual property rights.

2.2 Federated Synthetic Environments

In order to achieve interoperability, distribution, re-use and collaboration between simulations, FSEs use a systems-of-systems or federated approach to exchange data and share services between its components or federations. The study team adopted the following definition:

> "A Federated Synthetic Environment is a federation of M&S services, data services, tools etc. that is used to stimulate the System under Test and to collect, store, analyse, visualize T&E data."

An FSE is a system of multiple interconnected systems (usually software, although hardware-in-the-loop is an option) that work together to provide a comprehensive and collaborative environment for the System under Test (SUT). The simulations (colloquially, often referred to as "federates") can be connected via a number of architectures. All federates may be connected via a common data bus or layer, e.g., using HLA, but federates may also be connected directly to one another.

The SUT is the actual system that is to be tested and/or evaluated. In many cases, the SUT may be treated as a "black box". It is important to note that (data exchange) interfaces are usually dictated by the SUT, as the aim is to stimulate the SUT via its original interfaces. In other words, in general it cannot be assumed that an SUT has an interface that is usually common within synthetic environments, e.g., HLA or DIS.

An FSE has the following features:

- Interoperability: The different simulations in an FSE can interact with each other and exchange data, allowing for the simulation of complex and interrelated systems.
- Scalability: An FSE can be scaled to include a large number of simulations and entities, creating a more realistic and accurate representation of the system being simulated.
- Distributed: The simulations in an FSE can be distributed across multiple locations, allowing for large-scale and more realistic simulations.
- Human in the loop: An FSE can include human operators in the simulation, providing a more realistic and accurate representation of the system being simulated.
- Data collection: An FSE can be used to collect data from the different simulations, providing valuable insights for test and evaluation.
- Value for money: An FSE can provide a cost-effective way to test and evaluate new systems and equipment, reducing the need for expensive live testing, or enabling more sophisticated tests as compared to live testing alone.
- Flexibility: An FSE can be used to simulate a wide range of scenarios, from individual components to entire systems, and can be adapted to different test and evaluation needs.
- Representation: An FSE can represent the system being simulated in a way that is meaningful and understandable to the user.
- Secure: FSEs can be deployed on a variety of classification levels (potentially even in multi-level security environments) to provide information security and operational security that is sometimes difficult (or even impossible) to achieve in live environments.

Each of these features encourages re-use, open standards and collaboration, and in the processes will promote framework adoption and cost savings. Within a training context such a federated capability is often referred to as a "Live-Virtual-Constructive (LVC) Environment"; however, there is currently no direct or commonly used equivalent in the T&E domain.

2.3 Synthetic Environment Ecosystem

Rather than developing a small number of rigid, widely used FSEs, the desired step change in T&E demands a new approach for generating, deploying and using multiple FSEs to test and evaluate against emerging requirements. This step change in agility is required to enable T&E of multiple combinations of integrated systems, which cannot be assured using a reductionist approach, and to enable T&E to keep up with the pace of change in systems under test and environments. However, it should not come at the expense of reduced validity or increased cost. Instead, it is envisaged that this new approach will be enabled by a whole ecosystem of products, services and processes. For example, an ecosystem of SE content produced by multiple suppliers, with novel arrangements for IPR to facilitate re-use, catalogues for accessing content, tooling to compose this content into FSEs, runtimes, deployment and hosting services, and analytical tools.

The study team identified and compiled the following high-level requirements for FSEs for T&E and the SE ecosystem approach:

1. Maximise the range of potential SUTs, and combinations of them, that can be tested:
   - Test the performance of the full range of new and existing defence systems (including weapons, vehicles, IT, and other equipment) across all five domains (land, maritime, air, space, cyber).
   - Test the performance of these systems at multiple levels of detail (from components and sub-systems to their interoperability as systems-of-systems).
   - Test the performance of these systems at multiple Technology Readiness Levels, from early and entirely virtual designs to physical prototypes.
   - Evaluate the effectiveness of multiple combinations of these systems as systems-of-systems.
   - Evaluate the effectiveness of new tactics and strategies at each of the levels of detail described above (T&E for operational advantage).
   - Identify potential weaknesses in new and existing systems.
   - Test systems in isolation and in tandem, alongside small and large numbers of entities.
2. Maximise the range of potential environments, and combinations of them, in which SUTs can be tested:
   - Provide a safe and controlled environment that mimics real-world scenarios as closely as necessary. Depending on requirements, this may range from small, simple scenarios to very complex scenarios with lots of entities and interactions.
   - Provide the ability to test and evaluate the systems under various environmental conditions such as different weather, terrain, and time of day.
   - Analyse the potential outcomes of different military operations (T&E for advantage).
   - Allow for the testing of the system under realistic and simulated stress conditions.
   - Evaluate the performance of equipment under extreme conditions.
3. Provide high quality cost-effective test and evaluation
   - Provide the ability to test the systems in a cost-effective manner, reducing the need for expensive live testing.
   - Test the systems in a controlled and safe manner.
   - Be capable of being verified, validated and accredited (VV&A'ed). In case, full VV&A is not feasible to achieve (due to resource constraints or other limiting factors), it should be possible to achieve a certain "level of confidence", so that the usefulness and limitations of the generated results can be assessed.
   - Facilitate the collection, storage, and analysis of data, which can be used to improve the performance of the systems.

4. Maximise the number of users of (and hence beneficiaries of) the SE ecosystem for T&E:
   - Need to be easily accessible and usable by MOD and its industry, government and international partners to ensure that it is used to the fullest extent.
   - Creation of an SE ecosystem that is effective, promotes coherency and consistency, is readily sharable and reduces duplication of work.
   - Enables the rapid generation, deployment and use of federated synthetic environments.
   - Should consider methods to manage and protect Intellectual Property (IP) within the SE ecosystem for T&E whilst promoting the ability to share.
   - Allows any model or data set to be integrated into the SE ecosystem for T&E (though it is appreciated some models and tools will be easier to integrate than others).
   - Allow easy integration of SEs into the wider T&E ecosystem (including live testing).

It is important to note that the intent of the SE ecosystem for T&E is to minimize time and cost for setting up a T&E environment for a specific SUT. However, it is not expected that the elements of the SE ecosystem for T&E can always be integrated in a "plug-and-play" fashion, but that manual integration effort is required. The amount of integration will vary (depending on the use case, interface requirements, novelty of the SUT etc.), but in general the intent is to minimize this integration effort. Reduced integration efforts due to agreed standards, approaches and procedures may also help to alleviate issues with availability of suitably qualified and experienced personnel.

A stretch goal is the ability to re-use a FSE for T&E to enable military personnel to experience the use of new equipment, specifically early on in the process where the actual system might not yet exist, and in the evaluation and validation of various tactics, without the need for live training exercises.

2.4 Differences of simulation for T&E to simulation for training

In contrast, while simulation has been used very successfully in the conduct of T&E activities, these endeavours tend to be more isolated in nature and focused more on single scientific or experimental goals with less emphasis placed on reuse, standards and interoperability. In this respect, T&E covers a far broader scope of interest, endeavours and requirements than training. Table 2-1 illustrates the differences between SEs for training and SEs for T&E.

Table 2-1: Comparison of SEs for Training vs. SEs for T&E.

Characteristic	Training	T&E
Nature of the application domain	Often aimed at recurring iterations.	Often focussed on single scientific or experimental goals.
Human involvement	Training will always involve humans (at least one human participant as the subject of the training).	T&E may not include humans but only system-to-system interaction. Humans likely needed to run and control the tests but not necessarily be part of the tests.
System level	Training typically occurs at system (or sub-system) level upwards.	T&E will cover all levels from component through to Systems of Systems.

Types of simulation and data analytics tools used	All sorts of simulation used (live, virtual, constructive). Data analytics often constrained to After Action Review.	Often constructive, faster-than-real-time simulations are preferred to allow high numbers of repetitions. Sophisticated statistical analysis and data visualization used. Usually more scientific and critical in their analysis.
Models (and fidelity)	'Realistic enough' models to achieve training objectives.	T&E will often incorporate detailed physics-based models. Also, models may have to be formally verified and validated if used for certification of a SUT.
Complexity	Varies significantly depending on training purpose, but usually restricted to minimum required to achieve training objectives.	More varied and complex in nature.
Determinism	Exact repeatability usually not required.	Often repeatable and deterministic behaviour is required. Larger scale runs may be required for statistical validity.
User community	Predominantly soldiers in warfighting activities.	Large cross-section of users including scientists, academics, engineers (structural, electronic, chemical etc), designers, strategists etc.
Safety concerns		Safety will be more complex with T&E SEs when performing hardware in the loop testing, e.g., laser safety rooms, EM radiation exclusion areas. Physical safety measures will undoubtably be incorporated but there may also be safety features within the SE.

3.0 RELEVANT APPROACHES AND TECHNOLOGIES

An initial review has highlighted a couple of related national and international efforts.

3.1 UK national efforts

The study team identified the Defence Synthetic Enablers (DSEn) and Defence Synthetic Environments Platform (DSEP) programs as most relevant efforts that are related to the T&E efforts and where the T&E effort should aim to inject guidance.

DSEn is similar in nature to the ecosystem of models and data as envisioned for the T&E ecosystem. DSEn will provide Defence-wide access to common Modelling & Simulation (M&S) resources, across all M&S applications, through a Defence Simulation Centre (DSC) to support coherence and enable reuse, interoperability and Value for Money across the Defence Enterprise. DSEn will include a Defence

Simulation Centre Catalogue (DSCC) and a Synthetic Environment Service (SES) to generate, manage, maintain, store and provide Synthetic Environment data and 3D models optimised for M&S usage enabling sharing and reuse, with an ability for the service to evolve to cover other types of data specifically for M&S.

The DSEP programme is more akin to the tooling and runtime elements of a future T&E SE ecosystem. It is made up of four distinct areas; Service Integrator, Applications/use cases, Tooling/coding and a synthetic environment platform. The platform environment is a multi-agent programmable M&S development environment for building agent-based simulations. A scalable, agile platform to provide and exploit trusted and authoritative M&S data, government furnished assets, models, services and applications to produce pertinent synthetic environments for various use cases.

3.2 International efforts

The most relevant international effort identified by the study team are the NATO Modelling and Simulation Groups (NMSGs) efforts towards establishing an M&S as a Service (MSaaS) ecosystem. MSaaS is being investigated and matured by the NMSG, Nations, and Industry for many years. Early efforts (MSG-131, MSG-136) provided initial proof that MSaaS has great potential to efficiently realize future simulation environments for NATO and its Partners. MSG-164 further evolved the “Allied Framework for MSaaS” to enable subsequent S&T efforts as well as standardization and implementation, and the current MSG-195 study team matures MSaaS in an operationally relevant environment and conducts required research and development efforts. Figure 3-1 depicts the “Allied Framework for MSaaS”.

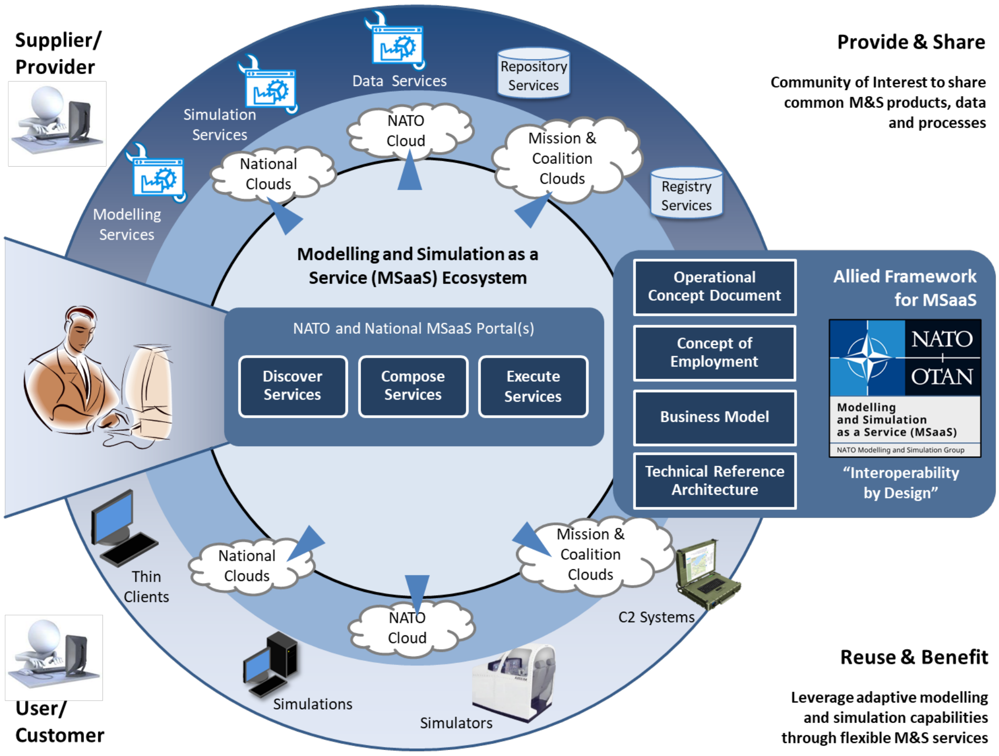

Figure 3-1: The Allied Framework for MSaaS. [5]

4.0 ARCHITECTURE OUTLINE FOR SE ECOSYSTEM FOR T&E

4.1 Overview

Figure 4-1 outlines the vision and overall architecture of a SE ecosystem for T&E. It is emphasized that this paper focuses primarily on the technical aspects of the architecture and the T&E Ecosystem. It does not focus on the broader aspects in terms of governance, protection of Intellectual Property Rights, business models etc. While these are important topics, they are out of scope of this paper.

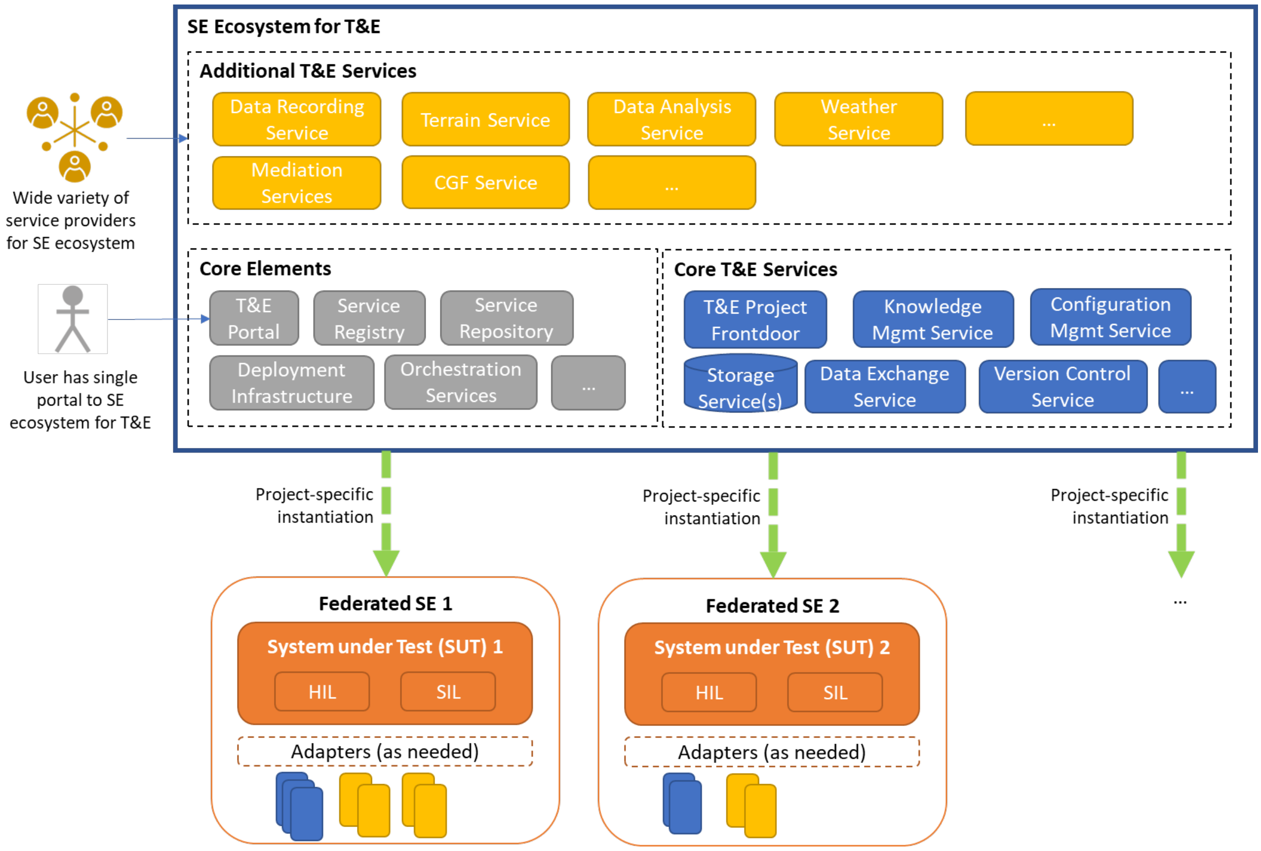

Figure 4-1: Architecture Outline for an SE ecosystem for T&E.

This architecture diagram deliberately makes no assumption as to who is "owning" (or is responsible for) individual parts (e.g., MOD or industry) of the T&E ecosystem. That said, determining (early views) on who owns & who would be part of the 'approach' need to be addressed in subsequent work.

4.2 Core Elements

Core Elements are an essential part of the SE ecosystem for T&E and must be in place. Table 4-1 outlines the Core Elements without predicating a solution in any way. Especially, the study team did not make a recommendation whether all Core Elements should be provided by a single provider or multiple providers.

Table 4-1: Core Elements of a SE ecosystem for T&E.

Core Element	Description	Benefits	Examples
T&E Portal	Single front-door to all T&E processes, data etc.	Ease of access	Aditerna SRP, Thales Nuada
Service Registry	Registry (catalogue) of available T&E services (M&S services, data services, tools etc.). Holds the metadata about available T&S services. Multiple instances possible that may be linked to each other.	Ease of access Federated ecosystem	Aditerna SRP, Thales Nuada, Envitia Horizon Various government-owned catalogues [6]
Service Repository	Repository of available T&E services. Holds the actual services (e.g., as virtual machine, container etc.). Often integrated with Service Registry, but may also be a separate system.	Ease of access Federated ecosystem	Harbor, Portainer, OpenStack, Aditerna SRP, Thales Nuada
Deployment Infrastructure	Infrastructure required for deploying T&E services (e.g., via virtual machines, containers).	Ease of access Scalability and Elasticity	Kubernetes, Docker, OpenStack Amazon AWS, Microsoft Azure, Google Cloud Platform Government-owned cloud infrastructure
Orchestration Services	Middleware required to 'glue' services together and execute a set of services as a coherent, meaningful federation (or 'composition').	Flexibility Reuse	Thales Nuada, Kubernetes, Docker, OpenStack

4.3 Core T&E Services

Core T&E Services (see Table 4-2) provide essential functionality that is anticipated to be required in each FSE built using the SE ecosystem. As any other service, the Core T&E services are managed through the available registries and repositories.

Table 4-2: Core T&E Services of a SE ecosystem for T&E.

Core T&E Services	Description	Benefits	Examples
T&E Project Frontdoor	Frontdoor for a specific T&E project. All processes, data etc. of this T&E project should be accessible through this frontdoor.	Ease of access	Aditerna SRP
Storage Service	Provides storage capacity for T&E data.	Scalability	Apache Hadoop, Amazon S3
Knowledge Management Service	Provides capabilities for knowledge management, e.g., wiki, test cases.		Atlassian Confluence, MediaWiki
Configuration Management Service	Provides capabilities for configuration management, e.g., keeping track of versions of the SUT, test cases, etc. Often includes version control.		Git, Bitbucket
Test Management	Provides capabilities for test management, e.g., defining and documenting test cases, creating test reports, etc.		National Instruments TestStand, Microfocus ALM, Polarion ALM, Squish
Data Exchange Service	Enables connectivity between federates within the synthetic environment to allow them to interoperate and exchange information using well described data. Should be based on open standards, such as HLA or DDS.	Re-use and integration	Pitch pRTI, MÄK, Portico, OpenDDS

4.4 Additional T&E Services

Additional T&E Services provide functionality that is required on a case-by-case basis by individual FSEs for T&E. Table 4-3 provides examples of additional T&E services that might be part of a future SE ecosystem for T&E.

Table 4-3: Examples of Additional T&E Services of a SE ecosystem for T&E.

Additional T&E Services	**Description**
Terrain Service	A number of services providing data and functions describing the T&E environment including aspects such as: • Elevation: Terrain height and line-of-sight. • Imagery: Terrain imagery data. • Material: Terrain material information service. • Obstacle Data: Including information about environmental features such as pylons, wind turbines, power lines etc. that might affect the system under test Includes Environment Database for storing environment datasets including digital terrain elevation, imagery data etc.
Weather Service	A number of services providing information on the state of the atmosphere.
Mediation Services	Gateways, adapters, etc.
Data Analysis Service	Enables analysis of recorded data.
Data Visualization	Enables visualization of data and results.
Comms & EMC degradation model	Modelling communications links and effects of EMC degradation (affected by weather data).
Terrain Interaction Services	Modelling the impact of aspects of the SE on the Environment's terrain representation, e.g. • Impact of weather on terrain material, e.g. precipitation on the terrain. • Impact of SE models on terrain
CGF Service	Providing the representation of the threat in the T&E system.
Real World Data	Services providing real-world data feeds, e.g., ADS-B, AIS data.
Data Recorder	Enables data exchange between SUT and the Synthetic Environment to be recorded and stored for later use
Human Behaviour Service	Specific service that models human behaviour, e.g., behaviour of commander of enemy forces in various situations, or behavior of crowds and local population in urban environments.

5.0 CONCLUSIONS AND OUTLOOK

5.1 Conclusions: The MSaaS Ecosystem is ready to be adopted by the T&E community

Over the last years, efforts within NATO and nations have advanced the state-of-the-art of MSaaS, and the training community (as a major user of simulation in the Armed Forces) is increasingly adopting MSaaS when acquiring new training systems or modernizing existing simulators. However, it is important to acknowledge that MSaaS is not a single technology (with a TRL) but a combination of various technologies in combination with a new business model and new governance structures. While some elements of MSaaS (such as the use of virtualization technologies, or individual services instead of monolithic systems) are common practice in commercial industries and are increasingly being adopted by the M&S community, other MSaaS elements (e.g., composability of services) are at a lower TRL and subject to ongoing research and development efforts.

Despite the broad spectrum of maturity of individual MSaaS elements, MSaaS is increasingly being adopted by the training and exercises community. In addition, communities such as Data Farming that are using M&S to support decision-making processes have successfully adopted MSaaS. In this regard, the T&E community is another community that can benefit from adopting MSaaS. The growing political demand for multi-national collaboration (e.g., next generation aircrafts, or the European Sky Shield Initiative) also drives T&E to a more international approach that is able to seamlessly integrate systems under test and FSEs (that stimulate the SUTs) from multiple sources including international partners.

5.2 Outlook: Towards Digital Twins and Continuous T&E

Digital twins are considered to be virtual representations of real-world entities and processes, synchronized at a specified frequency and fidelity. Digital twins are becoming increasingly important in the commercial sector for T&E of new software, equipment etc. and it is fair to assume that Defence can benefit heavily from Digital Twins as well. [7]

The expected benefits of digital twins for Defence include:

- Substantially reduced time, resources, and risk associated with the entire acquisition process;
- Increased quality, military worth, and supportability of fielded systems, while reducing total ownership costs throughout the total life cycle; and
- Enable Integrated Product and Process Development (IPPD) across the entire acquisition life cycle.

A key aspect of digital twins is the continuous synchronization of the digital twin with the represented real-world entities and processes. At the same time, the requirement to keep the digital twin in sync with the represented real-world system is the main challenge as it requires continuous efforts and maintenance of the digital twin.

Given the growing importance of Digital Twins, it is critical for any future FSE Ecosystem for T&E to be able to accommodate (and integrate) digital twins for future T&E efforts. The FSE Ecosystem for T&E outlined in this paper would form a building block towards using digital twins across Defence, thereby providing greater agility to respond to developing technical (and operational) threats in the real world and to leverage emerging opportunities from new technology.

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