MSaaS based architecture for Dynamic Synthetic Environments in Distributed Simulations

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ABSTRACT: *Real-world military operations take place in challenging and ever-changing environments. It is therefore important that modelling and simulation systems used to support defence, including planning and training for operations are capable of representing the dynamic aspects of real-world environments in a common and consistent way. This will increase the (training) value and realism of simulation exercises and help military personnel to better prepare for future operations.*

Current simulation systems only support limited capabilities of dynamic features, and where such capabilities are represented these are often pre-scripted and not correlated with other systems in a federated (distributed) simulation exercise. This gap between the need to represent the challenges of operational environments across simulation systems led to the formation of the NATO Task Group MSG-156, with the objective to research how a correlated Dynamic Synthetic Environment (DSE) can be achieved in future distributed simulations.

This paper will discuss the solution architecture that MSG-156 has proposed to achieve correlated dynamic synthetic environments. MSaaS is a key technology in this architecture as central services enable one synthetic environment state to exist for all participants. This includes the development of prototype services to support dynamic modifications to the environment to be made in a consistent way. The components of this proposed DSE architecture, their responsibilities and interfaces will be described.

MSG-156 carried out a proof-of-concept demonstration of the proposed DSE architecture. This paper will discuss the demonstration and the subsequent lessons learned from integrating the relevant service based components and executing the demonstration. Finally, the recommendations on further developments and standardization and potential exploitation of the DSE architecture will be discussed.

1. Introduction

The use of Modelling and Simulation (M&S) across NATO and NATO Nations is an increasing requirement in support of defence joint, collective and coalition training, capability development, mission planning and preparation, and decision support in acquisition processes. However, the representation of the Synthetic Environment (SE) in defence simulation systems does not cover the highly dynamic nature of these environments in real world operations. Current M&S practices, standards and technologies mainly achieve static representations of the outside world environment, based on common environmental datasets and re-using environmental databases.

NATO MSG-156 started in 2017 as a 3-year research Task Group (TG) to address the gap between the need to represent the challenges of real-world operational environments in M&S systems and existing technical capabilities, with the objective to research how a correlated Dynamic Synthetic Environment (DSE) can be represented in future distributed simulations [1]. Examples include the state of the natural environment which can affect force behaviour (e.g. effects of weather on ground vehicle trafficability), and the effects of military physical (kinetic) force behaviour on the state of the environment (e.g. terrain deformation, munition damage to buildings, infrastructure, etc.).

The TG first identified the requirements for a DSE and which elements of dynamic terrain and weather are most relevant to represent (see Section 2). The TG then defined a solution architecture aimed at achieving a correlated DSE (see Section 3). To get hands-on experience with this architecture a proof-of-concept demonstration was performed where various simulation systems and services supplied by the MSG-156 participating nations were connected in accordance with the DSE architecture. Section 4 discusses this concept demonstration in more detail. In section 5 the standardization status of the various interfaces used in the DSE architecture is discussed. Section 6 of this paper provides a summary on the conclusions and recommendations relevant to taking the DSE architecture forward

2. Requirements for Dynamic Synthetic Environments

MSG-156 has defined the high-level requirements for a DSE architecture by surveying existing capabilities, looking at relevant operational use cases that should be represented and by analysing conceptual modelling diagrams of the interactions within a DSE. This has resulted in requirements given below.

Requirements for a DSE architecture

- It should be possible to make changes to the synthetic environment at runtime during the simulation exercise.
- It should be possible to have the synthetic environment changes triggered by:
    - Processes within the environment itself, e.g. weather affecting terrain conditions
    - Events caused by participants of the exercise, e.g. the detonation of a weapon
    - The instructor or white cell operator of the simulation exercise
- The DSE architecture should support the inclusion of derived effects from the dynamic changes as well, e.g. destruction of a bridge is not only visual, but also affects the navigation of constructive entities.
- The DSE shall be sufficiently correlated, so that different participants in the distributed simulation make the same assessment of the situation within the mission.
- The DSE architecture should be vendor neutral.
- The DSE architecture should use open standards in accordance with the NATO M&S Standards Profile (NMSSP) [13] where appropriate.
- The DSE architecture should support terrain and weather data for land and air operations. Data for underwater operations, sea states, space weather or other planets is out of scope for the TG. The DSE architecture should be flexible enough though, so that additional data layers can be added to the concept later.

Requirements for dynamic terrain

- The dynamic terrain should be represented consistently to the different participants in the simulation exercise, e.g. the presence of craters or the damage to objects.
- The dynamic terrain should have a consistent effect on entities and their systems in the simulation exercise, e.g. on their trafficability or line of sight.
- The damage to objects should be consistent with the characteristics of the weapon that caused the damage.

Requirements for dynamic weather

- The weather should change with time and space during the simulation exercise.
- The weather should be represented consistently to the different participants in the simulation exercise.
- The DSE architecture should support representing weather effects on entities and their systems consistently in the simulation exercise, e.g. trafficability of ground vehicles or on the performance of sensors.
- The representation of weather in simulation systems should support either historical or live weather data from authoritative data providers.

In addition to these high-level requirements for a DSE architecture, the MSG-156 also investigated which dynamic terrain effects and which elements of the weather are most important to implement in a simulation exercise. For the dynamic terrain the prime effects that should be supported by the DSE architecture were identified as

- Deformations of the terrain surface, e.g. the creation of craters due to weapon detonations or combat engineering activities resulting in trenches.
- Damage of features and structures, e.g. damage to buildings and infrastructure due to weapon detonations, this does not only include the visual damage, but also aspects like a damaged road network affecting the route finding of entities.
- Trafficability, e.g. the impact that the terrain and weather conditions have on the ability of vehicle to move.

For the weather parameters it has been considered which parameters are most important for the visualisation of the weather, for the impact of the weather on platform dynamics and for the impact of the weather on the terrain state. The table below gives the weather parameters that should be supported by a DSE architecture as a minimum for these various weather usages.

Weather usage	**Relevant weather parameters**
Visualisation	Clouds Visibility / Fog / Haze Precipitation Wind speed and direction (for movement of clouds, waving of flags, ...) Temperate (affects IR sensor image) Humidity (affects sensor image)
Platform Dynamics	Wind speed and direction Precipitation Temperature Pressure Air Density
Terrain State	Precipitation Temperature

3. Solution architecture for Dynamic Synthetic Environments

The current paradigm for simulation systems is that each system is responsible to maintain its own state of the synthetic environment. This means that each system also has to modify their environment when dynamic changes occur. As having a correlated static environment over different simulation systems is already a big challenge that is hard to achieve, MSG-156 concluded that trying to achieve a correlated DSE in this current paradigm will be a near impossible challenge. Therefore, it was decided to define a DSE architecture that is based on the Modelling and Simulation as a Service (MSaaS) approach [2][3][4].

MSaaS allows the responsibility of maintaining the DSE state to be assigned to one single component, as there are common services that maintain the state of the terrain and the weather. All participants will retrieve their information about the environment from these services. This makes it easier to achieve a correlated representation of dynamic changes over different simulation systems. When modifications have to be made a modification service has the responsibility to make the changes to the terrain data. This has the benefit that the specialized knowledge about how these dynamic changes are made to the environment only have to be implemented in one service, instead of in each simulation system, which reduces the complexity of simulation systems.

Although the MSaaS approach offers many possible benefits for the DSE architecture, the MSG-156 TG also realised that this approach represents a major paradigm shift in the deployment and integration of future M&S systems and meaning that the DSE architecture cannot be deployed in the near future. Future M&S components first need to be modified to be able to consume their SE data from external services, instead from their local pre-computed terrain databases. However, given the potential benefits of the MSaaS, MSG-156 decided that pursuing this approach is the preferred solution.

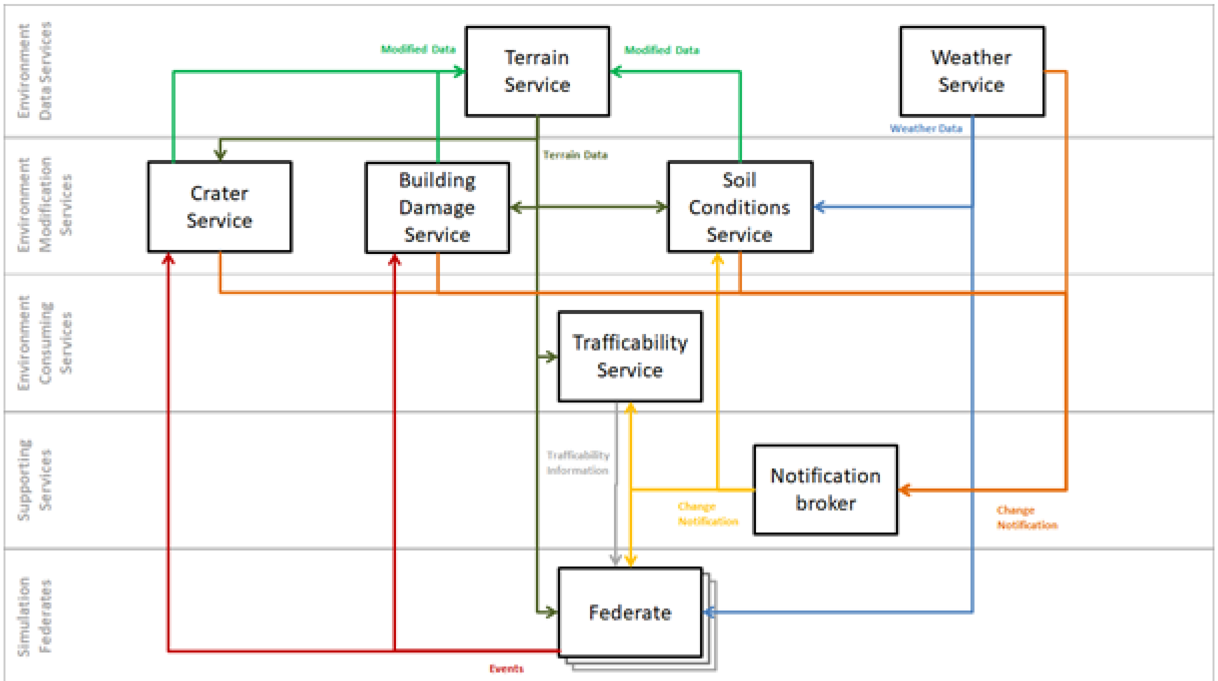

Figure 1: Architecture for DSE

Figure 1 shows the DSE architecture that has been defined by MSG-156. The involved components have been organised in the following layers, which will be discussed in more detail below:

- Environment Data Services
- Environment Modification Services
- Environment Consuming Services
- Supporting Services
- Simulation Federates

3.1 Environment Data Services

This layer contains the services that provide environment data to the other services and federates. Within the DSE architecture two distinct services to provide data have been identified, the Terrain Service and the Weather Service.

Terrain Service

The Terrain Service provides terrain data, such as imagery, elevation, vector or 3D content data, to the other participants in the simulation. The geographical data is provided using various standard from the Open Geospatial Consortium (OGC):

- Web Mapping Service(WMS) [5]
- Web Coverage Service (WCS) [6]
- Web Feature Service (WFS) [7]

To be able to also receive updates of the geographical data from other services, the Terrain Service should also support the OGC transactional standards [8]. When serving vector data, it is important that a common and agreed upon data model is used for the semantics and attributes of the vector data.

3D model content, including infrastructure objects such as roads, bridges, buildings and object damage states, should be provided in common formats to end user simulations. Currently, OpenFlight is the most commonly used format for this, but to be able to support dynamic updates to the model and to stream the content from the Terrain Service, it is foreseen that another format will be required in the future.

Weather Service

The Weather Service provides weather data, such as wind, clouds, precipitation or atmospheric conditions, to the other participants. For simulation federates using a High Level Architecture (HLA) a specific Federation Object Model (FOM) should be used to share weather data. Within the NATO Education and Training Network (NETN) a Meteorology and Oceanography (METOC) FOM is currently in development for this [9]. However for simulations or services that require weather data for a wider area, providing them as raster data via an OGC WCS interface should also be supported.

Where weather is represented in different ways, e.g. individual clouds versus cloud layers, based on the varying requirements of different simulation systems, the Weather Service should ensure as much correlation between those representations as possible.

3.2 Environment Modification Services

This layer contains services that are responsible to modify the state of the synthetic environment during the execution of the simulation. These services will provide the updated terrain data to the Terrain Service, so that all participants in the simulation can retrieve the current environment state from there.

In general, the modification services will retrieve the current terrain data from the Terrain Service, modify it for the dynamic aspect that they are responsible for and then provide the updated data back to the Terrain Service. Depending on the dynamic aspect they are responsible for the modification can be a recurring one, e.g. for the impact of weather on the soil condition, or an event based one, e.g. for a detonation that creates a crater.

Within the DSE architecture the following specific instances of an Environment Modification Services are foreseen:

- A **Crater Service** which updates the terrain data with craters based on detonations of weapons. The Crater service can modify the imagery, elevation and vector data of the terrain with the crater.
- A **Building Damage Service** which updates the damaged state of objects (buildings) based on detonations of weapons. A simple implementation of such a service selects between various representations (normal, damaged, destroyed) of the object and stores the state that should be used as an attribute in the terrain data. Higher fidelity implementations could physically deform the object based on the detonation and calculate the new appearance of the object.
- A **Soil Condition Service** which updates the soil condition based on the current weather. This service determines the moisture level of the soil and the presence of puddles, depending on the amount of precipitation. The resulting soil conditions are stored in the Terrain Service, so that they can be used as inputs for trafficability calculations.

3.3 Environment Consuming Services

This layer contains services that consume terrain data to be able to provide a certain service to participants of the simulation. In the current DSE architecture a Trafficability Service is included in this group, but in the future other functionality that depends on terrain data can be provided in such a way as well, such as a Line-of-Sight service.

The Trafficability Service is responsible to calculate the trafficability for all vehicles within the simulation exercise. Performing this as a central service, ‘fair fight’ is improved. These trafficability calculations use the current state of the terrain as input. The simulation systems will request the trafficability for a certain vehicle type at a given location and then receive the speed-made-good (maximum speed given the current terrain conditions) as answer. It is foreseen that in the future models confirming to the Next Generation NATO Reference Mobility Model (NG-NRMM) [10] can be employed within a Trafficability Service.

3.4 Supporting Services

This layer contains supporting services that are used to let the DSE services and the simulation systems work together efficiently. In the current DSE architecture the Notification Broker is the only service in this group. When an Environment Modification Service has made a change to the environment, it is required that all participants are informed that dynamic changes have occurred, as they can then request the up-to-date environment data. To prevent a tight coupling between the simulation systems and the services, a Notification Broker has been introduced in between. In this way the simulation systems and services can subscribe to updates about dynamic changes to the environment, without needing to know which concrete service produced them. Since it is foreseen that the simulation systems and services are not all part of the HLA federation, it is recommended that the Notification Broker also acts as a gateway for notification between the HLA federation and web technologies used by certain services.

3.5 Simulation Federates

This last layer contains all the simulation federates that will be consuming the dynamic environment data. This includes

Human-in-the-Loop (HITL) simulation systems, Computer Generated Forces (CGFs), stealth viewers and Instructor Operator Stations (IOS). These federates will also generate the event, like detonations, that cause certain dynamic changes to the environment.

4. Concept demonstration

To verify if the DSE architecture works in practise and to identify which aspects of the architecture need further research and standardization, MSG-156 performed a concept demonstration of the DSE architecture. In this concept demonstration simulation systems and services from the nations participating in the TG were connected according to this architecture, and a simulated mission that included dynamic changes to the environment was performed within this distributed simulation. Figure 2 shows some of the systems that were involved.

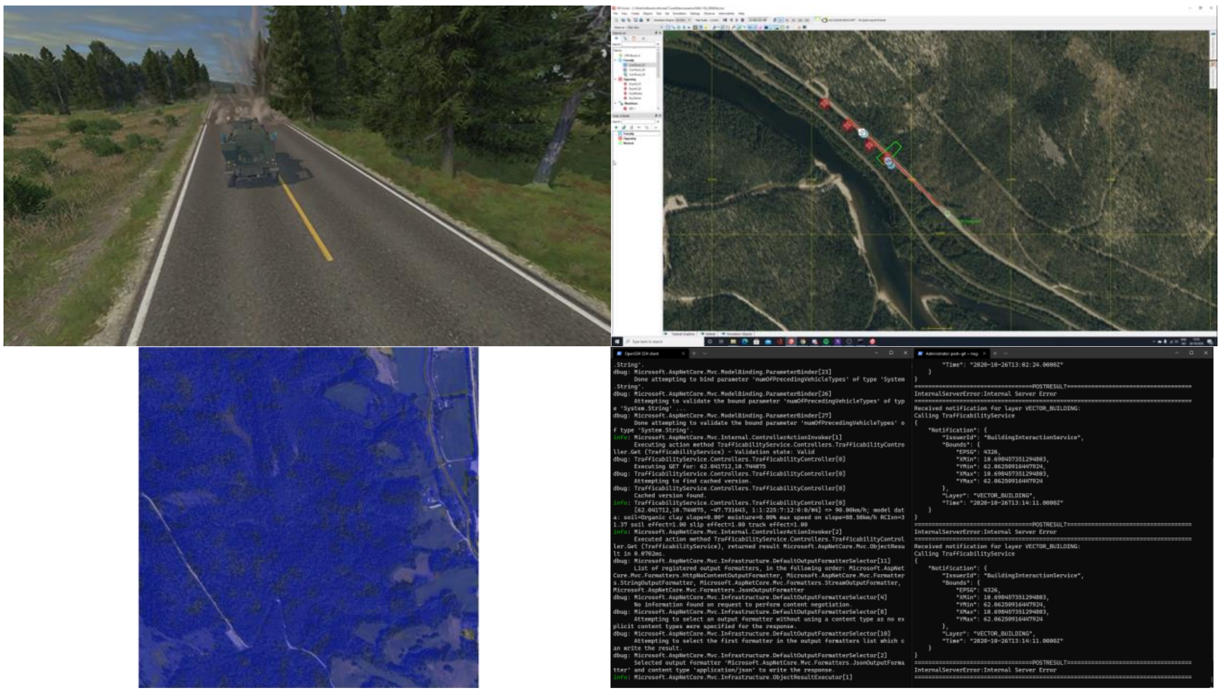

Figure 2: Examples of systems involved in the concept demonstration. Top left: Manned Vehicle Simulator, top right: Computer Generated Forces tool, bottom left: Soil moisture levels calculated by Soil Condition Service, bottom right: Trafficability Service.

A convoy protection scenario was used in the concept demonstration. A convoy is travelling from its camp to a forward operating base (FOB) and the planned route partly uses unpaved roads. Due to deteriorating weather the convoy gets stuck on these unpaved roads and has to take a detour via paved roads, which takes them closer to the insurgent area. Along that route they are ambushed with an IED and insurgents fire mortars at them, resulting in craters along the road. With the help of close air support the insurgents are attacked, where the dynamic weather forms a challenge for the pilot to find and engage the insurgents. Once the threat is neutralized the convoy can safely continue to the FOB. Within this scenario various dynamics environment aspects are involved: trafficability, terrain deformations, object damage and weather impact on sensors. Figure 3 gives a graphical representation of the scenario. MSG-156 has also made a video of this demonstration [11].

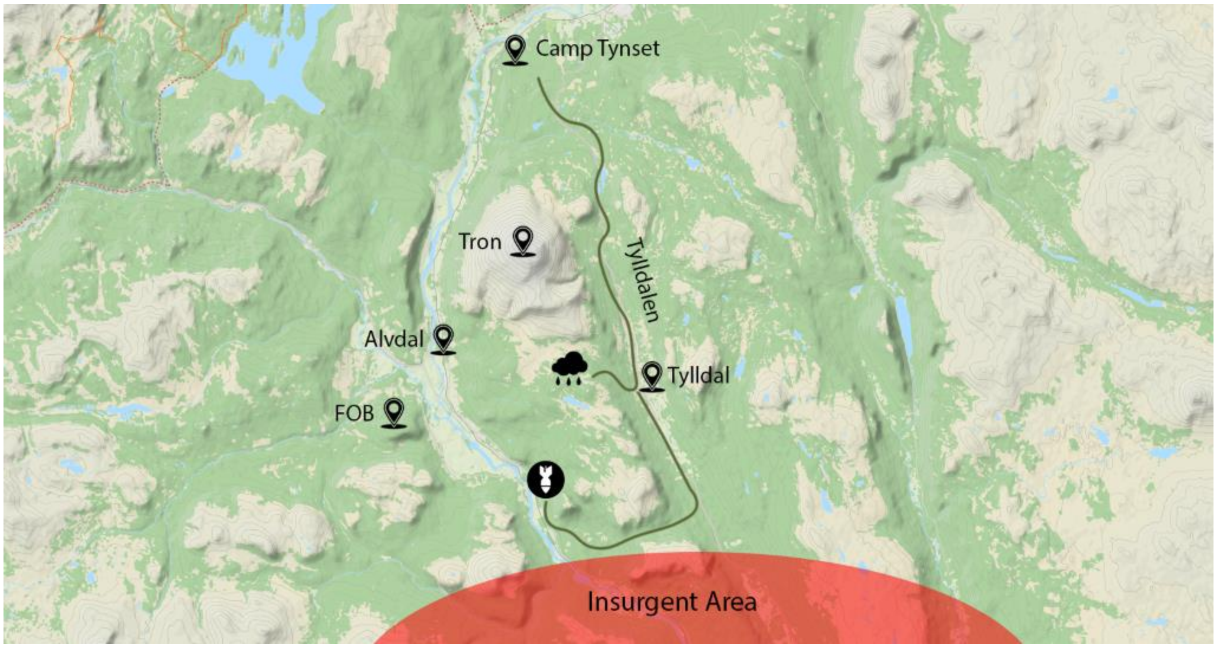

Figure 3: Scenario used in the concept demonstration

The concept demonstration has shown that it is possible to create a consistent DSE using a MSaaS based architecture. Introducing the dynamic changes from Environment Modification Services has shown the benefit of only having to make the dynamic changes in one location, which improves the correlation between different simulation systems. The use of a Trafficability Service provided a capability to achieve a consistent representation of the impact of weather on the trafficability of vehicles.

For simulation systems and services to be able to consume environment data from the Terrain Service and Weather Service they had to be modified. Since the M&S assets used were either prototype implementations developed for the demonstration, or R&D assets that could be modified or assets for which the company that developed them was involved in the TG, it was possible to modify them all for the DSE architecture. This showed that the DSE architecture is a paradigm change which requires existing systems to be modified.

The concept demonstration has also shown that just sharing weather data from a Weather Service is not sufficient to ensure a correlated representation of the weather in the simulation exercise. Different simulation systems have different capabilities when it comes to representing the weather, so even when they are provided with the same weather data a consistent (visual) representation is not ensured. Using the same METOC FOM is not sufficient to address this issue. The Weather Service should assist in achieving correlation, for example by ensuing that cloud layers and individual clouds that are provided are consistent with each other.

MSG-156 does realize that the concept demonstration was performed with a limited number of assets, so to be able to draw conclusions about the scalability and performance of the DSE architecture in a larger scale simulation, additional experimentation needs to be performed.

5. Standardization of interfaces

The concept demonstration of MSG-156 has shown that an MSaaS based architecture to achieve a correlated DSE is feasible. However, to implement such an architecture in operational M&S systems it is important that the interfaces between the various systems and services are standardized. This section describes which standards currently exist or are in development and where standards need to be developed, relevant to supporting interfaces for the DSE architecture.

- The OGC WMS/WCS/WFS standards are sufficient to provide terrain data from the Terrain Service to other services and systems. When the OGC transactional standards are used it is also possible for the Environment Modification Services to provide updates of the terrain data to the Terrain Service.

- To make it easier to the consumers to use the vector data provided by the Terrain Service, it is recommended to use a standardized data model for the vector data. Existing standards like SEDRIS or DFDD do provide elements to construct such a data model from, but none covers all the needs of a DSE. The SISO RIEDP standard [12], that is currently in development, is considered a promising candidate to be used for this data model.
- Content, such as 3D models, are typically provided in the OpenFlight format at the moment. This format does however not support all future needs, like dynamically updating objects or being able to stream them from the Terrain Service. Therefore, it is recommended to look for another format for 3D content that meets these needs. For example, by looking at standards used in the game industry and amending them with M&S specific needs. Such a development could possibly be aligned with future RIEDP developments, as a RIEDP dataset also contains 3D content.
- The NETN METOC FOM that is being developed by MSG-163 is a good starting point for sharing weather data within a distributed simulation. It has to be ensured however that the FOM supports the various weather representations that simulation systems use. For applications that require weather data for a big area, it is recommended to support providing them as raster data as well. In that case, the OGC WCS standard should be used again.
- The Trafficability Service is a new service, the communication between simulation systems and this service should be standardized. It is recommended that the data model for this interface is standardized. The interface could then be implemented using web technologies or as an HLA FOM depending on the needs to the distributed simulation.
- The Environment Modification Services that calculate craters and damage to objects require no additional standardization. The RPR FOM supports the events that cause these modifications, e.g. a detonation and storing modified terrain data is covered by the transactional OGC standards.
- A need has been identified for various services to notify other services and simulation systems about updates that have been made to the terrain data. It is recommended to develop a standardized data model for such notifications, which can then be used by various services. This need is not specific to DSE applications only, but could be relevant for any MSaaS based service. It could be investigated if such a notification schema is in line with the scope of the existing Cloud Based M&S (CBMS) SSG at SISO.

6. Conclusions and recommendations

The MSG-156 task group has concluded that a MSaaS based DSE architecture provides a solution to support coherent dynamic changes to the synthetic environment in distributed simulations. Continuing in the current paradigm where each system is responsible to update its own environment will not result in a consistent dynamic environment over different simulation systems.

A DSE solution architecture has been defined and the concept demonstration that was performed has shown that this architecture is feasible. It is possible to serve environment data from a Terrain Service and Weather Service to the participants and this does ensure that everybody uses the same environment data. It is also possible to use Environment Modification Services to make dynamic changes to the environment state and making one service responsible for this ensures a consistent representation of these changes for all participants.

MSG-156 also recognises that the concept demonstration was performed with a limited number of M&S assets, which means that a larger scale experiment is needed to validate the performance and scalability of the DSE architecture. The TG also realizes that it is a big paradigm change to provide the environment data from services, which means that existing simulation systems need to be modified to be able to cooperate with the services in the DSE architecture. Furthermore, not all interfaces that are used in the DSE architecture are standardized at this moment and it is therefore not foreseen that such a solution can be available for use in the near future.

It is recommended that the following interfaces need further research and development, including the development of standards where appropriate,

- the interfaces between the Trafficability Service and the simulation systems that simulate vehicles.
- the notification interface between Environment Modification Services and the simulation systems and services that are consuming the environment data.

- the METOC FOM used to provide weather data from the Weather Service, it needs to be ensured that the various representations of weather are supported by this FOM.
- the data model used to describe the semantics and attributes of the vector data of the terrain.
- the formats used to provide 3D content (e.g., building models), as the formats that are currently commonly used to not support dynamic changes and streaming of content very well.

In parallel to these standardization developments it is recommended to perform further experimentation to verify that the DSE architecture scales perform in an environment with a large number of assets and entities.

Once these activities have been performed the TG foresees that the DSE architecture for distributed simulations can be implemented into operational simulation systems, e.g. training systems. Given the modifications that are needed to support a DSE architecture, it is foreseen that the DSE capability will initially be included mainly in new simulation systems or during major updates of existing systems.

Once enough simulation systems have made the transition to support the DSE architecture, it will become possible to have a correlated dynamic synthetic environment in distributed simulation systems. This allows simulation systems to represent the challenges that the dynamic nature of the real-world environment provides much more accurate, and as a result of which the training and research value of these systems will increase.

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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 (TTEP) Project. This work is investigating processes and technologies aimed at achieving greater coherence and improved representation of emergent operating domains across defence synthetic based training systems, including the representation of human and autonomous systems behaviour and operational effects on behaviour.