NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-MSG-136-Part-VI**

Modelling and Simulation as a Service, Volume 3: MSaaS Engineering Process

(Modélisation et simulation en tant que service, volume 3 : processus d'ingénierie de la MSaaS)

Developed by NATO MSG-136.

Published July 2019

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

ABB	Architecture Building Block
BOM	Base Object Model
BSON	Binary JavaScript Object Notation
C2	Command and Control
C3	Consultation, Command, and Control
COI	Community of Interest
DIS	Distributed Interactive Simulation
DMAO	DSEEP Multi-Architecture Overlay
DSEEP	Distributed Simulation Engineering and Execution Process
FEAT	Federation Engineering Agreements Template
HLA	High Level Architecture
ISSOT	Industry Standard Service-Oriented Technology
IT	Information Technology
JSON	JavaScript Object Notation
LCIM	Levels of Conceptual Interoperability Model
M&S	Modelling & Simulation
MSaaS	M&S as a Service
MSaaS-EP	MSaaS Engineering Process
QoS	Quality of Service
RA	Reference Architecture
SDEM	Simulation Data Exchange Model
SOA	Service-Oriented Architecture
SOCCI	Service-Oriented Cloud Computing Infrastructure
TENA	Test and Training Enabling Architecture
V&V	Verification and Validation

Nomenclature

Composed Simulation Services	Are the results of composing simulation services. They offer entire simulations as services [2].
M&S Certification Services	Are technical services that provide capabilities to verify compliance of Simulation Services, Composed Simulation Services, or M&S User Applications with NATO interoperability standards for M&S [2].
M&S Composition Services	Provide the capabilities to compose and execute a simulation from existing simulation services [2].
M&S Enabling Services	Provide capabilities to create a simulation in which M&S Services and M&S User Applications are brought together to fulfil the purpose of that simulation [2].
M&S Information Services	Provides the capabilities to manage repositories of simulation service components and to manage references to authoritative information required for execution of simulations [2].
M&S Integration Services	Provide the infrastructure to connect producers and consumers of information and support an efficient and time coherent exchange of simulation messages between producers and consumers [2].
M&S Mediation Services	Provide broker and gateway services between incompatible producers and consumers of simulation-pertinent information. M&S Mediation Services receive data from information producers and transform it into a representation that is understood by the consumer [2].
M&S Message-Oriented Middleware (MOM) Services	Provide the capabilities for an efficient and time coherent exchange of messages between producing and consuming Simulation Services, independent of the message format and message content [2].
M&S Registry Services	Provide the capabilities to store, manage and retrieve references to authoritative information required for the execution of M&S Services, M&S-Enabling Services and M&S Applications [2].
M&S Repository Services	Provides the capabilities to store, retrieve and manage M&S Services, M&S Enabling Services and M&S Applications, and associated metadata, including descriptions of the interface and contract, information about QoS policies and security and versioning information [2].
M&S Security Services	Provide the capabilities to implement and enforce security policies for M&S Services [2].
M&S User Applications	Are a set of capabilities that provide user-facing functionality to M&S Enabling Services or M&S Services. User applications are to be understood in the SOA sense as loosely coupled front-end services that can be put together readily and rapidly for the purpose at hand [2].

MSaaS Customer	A defence organization with an operational need (e.g., training, mission planning, acquisition), and is the budget holder [1].
MSaaS Implementation	The specific realization of M&S as a Service by a certain organization as defined in the Operational Concept Document. An MSaaS Implementation includes both technical and organizational aspects [1].
MSaaS Provider	Makes M&S products and services (including integrated services, such as executable simulations) available to Users of the Allied Framework for MSaaS [1].
MSaaS User	The consumer of MSaaS products and services. The User may take responsibility for the composition and integration of M&S products and services in accordance with Customer requirements. There are different types of User that can be considered in the context of the Allied Framework for MSaaS [1]: • Operational End Users who define their capability needs to the Customer and who benefit from M&S products and services; and • Simulation Operators who use MSaaS products and services to provide simulation capabilities and applications to the Operational End User.
Modelling Applications	Are ABBs that specify front-end functionality for accessing the Modelling Services through the MSaaS Portal [2].
Modelling and Simulation (M&S) Services	Provide unique computing and information services for modelling and simulation support to operations. The M&S Services provide capabilities for the development and synthetic representation of (real-world) objects and events [2].
Modelling Services	Are a category of services that encompass the entire suite of architecture tools, modelling tools, development tools, visual composition tools, assembly tools, methodologies, debugging aids, instrumentation tools, asset repositories, discovery agents, and publishing mechanisms needed to construct a Simulation Service [2].
Simulation Applications	Are ABBs that specify front-end functionality which enable users to interact with Simulation Services and Composed Simulation Services. Such applications can be combined to give simulation front-ends in operational systems or in dedicated simulation viewers [2].
Simulation Control Services	Provide the capability to provide input to a simulation execution, control the simulation execution, and collect output from the simulation execution [2].
Simulation Scenario Services	Provide the technical capabilities to manage the simulation of scenarios [2].
Simulation Services	Provide a set of capabilities for synthetic representation of (real-world) objects and events. Simulation Services are the service-oriented building blocks of simulations [2].

Conventions

The following typographic conventions are used in this document:

- When a phrase is emphasised, a **bold** font is used;
- When a topic is emphasised, the First Letter(s) are capitalised;
- When a term or concept must be emphasised, an *italic* font is used;
- To indicate one single character, the quotation marks ‘and’ are used; and
- To indicate quotes/citations, the quotation marks “and” are used.

The first letters of Architecture Building Block (ABB) names are capitalised. The first letters of a solution for (i.e., realisation of) an ABB are not capitalised; e.g., Simulation Services (the ABB name), and simulation services (indicating solutions for this ABB).

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Modelling and Simulation as a Service, Volume 3: MSaaS Engineering Process

(STO-TR-MSG-136-Part-VI)

Executive Summary

NATO and nations use simulation environments for various purposes, such as training, capability development, mission rehearsal and decision support in acquisition processes. Consequently, Modelling and Simulation (M&S) has become a critical capability for the alliance and its nations. M&S products are highly valuable resources and it is essential that M&S products, data and processes are conveniently accessible to a large number of users as often as possible. However, achieving interoperability between simulation systems and ensuring credibility of results currently requires large efforts with regards to time, personnel and budget.

Recent developments in cloud computing technology and service-oriented architectures offer opportunities to better utilize M&S capabilities in order to satisfy NATO critical needs. M&S as a Service (MSaaS) is a new concept that includes service orientation and the provision of M&S applications via the as-a-service model of cloud computing to enable more composable simulation environments that can be deployed and executed on-demand. The MSaaS paradigm supports stand-alone use as well as integration of multiple simulated and real systems into a unified cloud-based simulation environment whenever the need arises.

NATO MSG-136 ("Modelling and Simulation as a Service (MSaaS) – Rapid Deployment of Interoperable and Credible Simulation Environments") investigated the new concept of MSaaS with the aim of providing the technical and organizational foundations to establish the *Allied Framework for M&S as a Service* within NATO and partner Nations. The *Allied Framework for M&S as a Service* is the common approach of NATO and Nations towards implementing MSaaS and is defined by the following documents:

- Operational Concept Document;
- Technical Reference Architecture (including service discovery, engineering process and experimentation documentation); and
- Governance Policies.

MSG-136 evaluated the MSaaS concept in various experiments. The experimentation results and initial operational applications demonstrate that MSaaS is capable of realizing the vision that M&S products, data and processes are conveniently accessible to a large number of users whenever and wherever needed. MSG-136 strongly recommends NATO and Nations to advance and to promote the operational readiness of M&S as a Service, and to conduct required Science and Technology efforts to close current gaps.

This document describes the MSaaS Engineering Process to be executed by NATO organizations building a Composed Simulation Service within and existing MSaaS implementation. It mirrors the structure of the Distributed Simulation Engineering and Execution Process (DSEEP) and provide guidance specific to developing M&S Services.

Modélisation et Simulation en Tant que Service, Volume 3 : Processus d'Ingénierie de la MSaaS

(STO-TR-MSG-136-Part-VI)

Synthèse

L'OTAN et les pays membres utilisent les environnements de simulation à différentes fins, telles que la formation, le développement capacitaire, l'entraînement opérationnel et l'aide à la décision dans les processus d'acquisition. Par conséquent, la modélisation et simulation (M&S) est devenue une capacité cruciale pour l'Alliance et ses pays membres. Les produits de M&S sont des ressources extrêmement précieuses ; il est essentiel que les produits, données et procédés de M&S soient facilement accessibles à un grand nombre d'utilisateurs aussi fréquemment que possible. Toutefois, l'interopérabilité entre les systèmes de simulation et la crédibilité des résultats ne sont pas encore acquises et nécessitent beaucoup de temps, de personnel et d'argent.

Les évolutions récentes du cloud informatique et des architectures orientées service offrent l'occasion de mieux utiliser les capacités de M&S afin de répondre aux besoins cruciaux de l'OTAN. La M&S en tant que service (MSaaS) est un nouveau concept qui inclut l'orientation service et la fourniture d'applications de M&S via le modèle « en tant que service » du cloud informatique, dans le but de proposer des environnements de simulation plus faciles à composer et pouvant être déployés et exécutés à la demande. Le paradigme du MSaaS permet aussi bien une utilisation autonome que l'intégration de multiples systèmes simulés et réels au sein d'un environnement de simulation dans le cloud, chaque fois que le besoin s'en fait sentir.

Le MSG-136 de l'OTAN (« Modélisation et simulation en tant que service (MSaaS) – Déploiement rapide d'environnements de simulation crédibles et interopérables ») a étudié le nouveau concept de MSaaS afin de fournir les bases techniques et organisationnelles permettant d'établir le « cadre allié de M&S en tant que service » au sein de l'OTAN et des pays partenaires. Le cadre allié de M&S en tant que service est la démarche commune de l'OTAN et des pays visant à mettre en œuvre la MSaaS. Il est défini dans les documents suivant :

- Document de définition opérationnelle ;
- Architecture de référence technique (incluant la communication du service, le processus d'ingénierie et la documentation d'expérimentation) ; et
- Politiques de gouvernance.

Le MSG-136 a évalué le concept de MSaaS au moyen de diverses expériences. Les résultats d'expérimentation et les premières applications opérationnelles démontrent que la MSaaS est capable de rendre les produits, données et processus de M&S commodément accessibles à un grand nombre d'utilisateurs, quels que soient l'endroit et le moment où le besoin s'en fait sentir. Le MSG-136 recommande vivement à l'OTAN et aux pays de faire progresser et d'améliorer l'état de préparation opérationnelle de la M&S en tant que service et de mener les travaux de science et technologie requis pour combler les lacunes actuelles.

Ce document décrit le processus d’ingénierie de la MSaaS que les organismes de l’OTAN devront suivre pour construire un service de simulation composé au sein d’une mise en œuvre existante de MSaaS. Il reflète la structure du processus réparti d’ingénierie et d’exécution de la simulation (DSEEP, *Distributed Simulation Engineering and Execution Process*) et prodigue des conseils propres au développement de services de M&S.

Chapter 1 – INTRODUCTION

The MSaaS Operational Concept Document (OCD) [3] describes the intended use, key capabilities and desired effects of the Allied Framework for M&S as a Service from a user's perspective.

The Allied Framework for M&S as a Service enables:

1) The community of users to discover new opportunities to train and to work together.
2) Users to enhance their operational effectiveness, saving costs and effort in the process. By pooling individual user's requirements and bundling individual requests in larger procurement efforts, the position of buying authorities against industrial providers is strengthened.
3) M&S services that are readily available on-demand and deliver a choice of applications in a flexible and adaptive manner. It offers advantages over the existing stove-piped M&S paradigm in which the users are highly dependent on a limited amount of industry partners and subject matter experts.

If the above capabilities are to be realized, NATO simulation engineers must have a well-developed and documented process for bringing them into being. The OCD identifies this requirement in Figure 1-1.

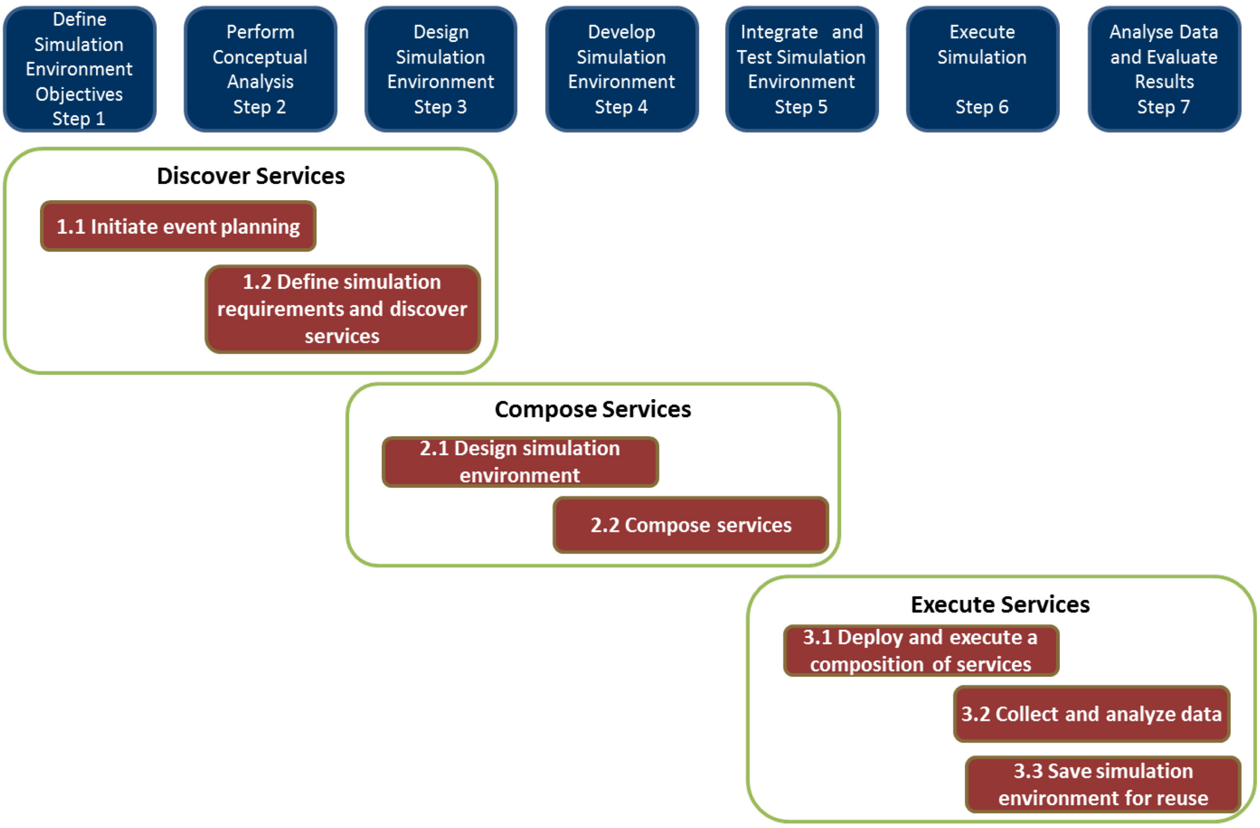

Figure 1-1: This Figure, Taken from the MSaaS Operational Concept Document, Shows the Alignment of Engineering Activities with the DSEEP.

This document, the MSaaS Engineering Process (MSaaS-EP), defines that process. However, it is important for engineers to understand the larger set of engineering environments and processes in which it is executed.

The MSaaS-EP is executed within an existing MSaaS Implementation, the specific realization of M&S as a Service by a certain organization as defined in the Operational Concept Document. An MSaaS Implementation includes both technical and organizational aspects [3]. The Allied Framework for Modelling and Simulation as a Service (MSaaS) Governance Policies [1] establishes policies that guide the development of an MSaaS implementation. This implementation will include implementations of M&S Enabling Services, which provide capabilities to create a simulation in which M&S Services and M&S User Applications are brought together to fulfil the purpose of that simulation.

The MSaaS-EP is executed to build Composed Simulation Services compliant with the MSaaS Reference Architecture (RA). The MSaaS RA [2] defines a set of architectural building blocks and architectural patterns to support the MSaaS-EP.

The services used during the MSaaS-EP to construct a composed simulation service are catalogued using the M&S Registry Services. Volume 2 to of the MSaaS technical documentation, Discovery Service and Metadata [4], defines the data standards that allow service discovery in and MSaaS implementation.

The MSaaS-EP mirrors the IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP). The documentation of the MSaaS-EP assumes engineering knowledge of the DSEEP [5], and it will only address the MSaaS specific engineering considerations during DSEEP execution.

If the MSaaS-EP is executed in a multi-architecture environment, it will also mirror the DSEEP Multi-Architecture Overlay (DMAO). The documentation of the MSaaS-EP also assumes knowledge of the DMAO [6]. As multi-architecture compositions are discussed, it will only address MSaaS specific engineering considerations in the context of the DMAO.

In short, this MSaaS Engineering Process covers the engineering necessary to develop composed simulation services within an MSaaS implementation, but it does not cover the engineering necessary to develop and maintain an MSaaS implementation within the organization. It assumes that this work has been done as part of its MSaaS governance process [1]. An organization developing composed simulation services must separately manage the lifecycles of composed simulation services and simulation services. Figure 1-2 updates Open Group's SOA Governance Framework to make the distinction [7].

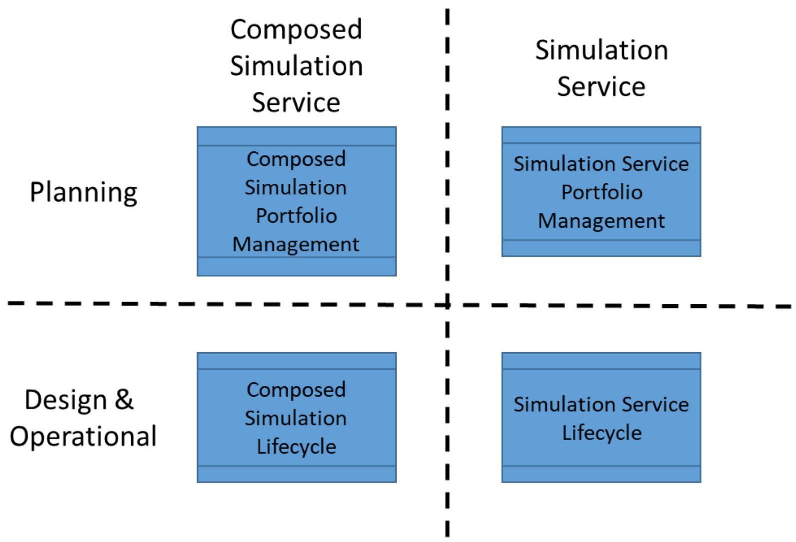

Figure 1-2. Simulation Development Processes Governed by SOA Governance.

A composed simulation service is composed of multiple simulation services. Simulation services are brought into being and managed across their lifecycle according to MSaaS Governance Policies that implement MSaaS principles. Service reuse principles make it very likely that a single simulation service will be a component of multiple composed simulation services. The organization's MSaaS Governance Policies will ensure that each simulation service is developed according to its architecture standards for service description, service monitoring, and service security. In this environment, a Composed simulation service may be designed and developed for a specific simulation purpose and lifecycle. This MSaaS overlay to the DSEEP covers the planning and design and development phases of a composed simulation service as depicted on the left side of Figure 1-2. Within the development of a composed simulation service, it may be necessary to develop new simulation services as components. If so, those services should be developed and maintained in the service governance environment on the right side of Figure 1-2, so that service can be reused in future simulation solutions. The accompanying NATO MSaaS Governance Policies describe best practices and policies for MSaaS governance [1]. The savings associated with service reuse is one of the key advantages for implementing a composed simulation service within MSaaS Governance Policies and infrastructure.

An MSaaS provider must execute the steps of the DSEEP while also paying attention to the architectural concepts outlined in the NATO Reference Architecture for MSaaS [2]. A well-executed deployment of M&S Services will take advantage of better alignment with operational functions, modular construction, and a service discovery architecture in order to enable reuse. The approach delivers more agility, faster development time, and reduced cost. In this MSaaS Engineering Process, it is important to focus first on capabilities required of a service before actually developing those services. This line of thinking enables clear articulation of the service contract and enables development of alternative technical solutions to fulfil that contract. For example, two entity movement algorithms could fulfil the same service contract with different levels of resolution.

The development of a composed simulation service will require the realization of many Architecture Building Blocks (ABBs), which are part of a reference architecture. This document will refer to the NATO Reference Architecture for MSaaS [2] as those ABBs are discussed. Table 1-1, pulled from the reference architecture, lists the ABBs per layer with references to the DSEEP activity to which they apply.

Table 1-1: Architectural Building Blocks of the NATO MSaaS Reference Architecture Organized into the Layers of the Open Group SOA Reference Architecture.

Layer	ABB	Referenced in DSEEP Activity
9) Governance Layer.	M&S Repository Services.	3.1, 3.3, 4.2, 4.3
8) Information Layer.	M&S Registry Services.	3.1, 3.3, 4.2, 4.3
7) Quality of Service Layer.	M&S Security Services.	2.3, 3.3, 4.4
	M&S Certification Services.	2.3, 5.2, 5.3
6) Integration Layer.	M&S Message-Oriented Middleware Services.	2.3, 3.2, 4.1, 4.2, 5.3
	M&S Mediation Services.	2.3, 3.2, 4.1, 4.2, 4.4, 5.3, 6.2
5) Consumer Layer.	Modelling Applications.	2.3, 4.1, 4.3
	Simulation Applications.	2.3, 4.1

Layer	ABB	Referenced in DSEEP Activity
4) Business Process Layer.	Composed Simulation Services.	All
	M&S Composition Services.	2.3, 4.4, 5.3
	Simulation Control Services.	2.3, 3.2, 4.1, 4.2, 4.4, 5.3, 6.1
	Simulation Scenario Services.	1.2, 2.1, 4.1
3) Services Layer.	Modelling Services.	4.3
	Simulation Services.	2.3 – 6.1
2) Service Components Layer.	SOA Platform Services (see C3 Taxonomy).	2.3, 4.4
1) Operational Systems Layer.	Infrastructure Services (see C3 Taxonomy).	2.3, 3.4, 4.4, 5.2, 6.1, 6.2
	Communication Services (see C3 Taxonomy).	

It is also likely that the service deployment target will be a cloud environment, enabling on-demand access, broad network availability, rapid elasticity to meet simulation computing demands, and resource pooling to achieve economies of scale. The Open Group has also developed Service-Oriented Cloud Computing Infrastructure (SOCCI) Framework [8]. An MSaaS provider should be aware of the synergies between SOA and cloud computing and the additional architectural building blocks for a cloud environment.

Chapter 2 – M&S AS A SERVICE CONSIDERATIONS FOR EXECUTING THE DSEEP

The purpose of the DSEEP is "to describe a generalized process for building and executing distributed simulation environments" [5]. In that light, the MSaaS Engineering Process described in this document assumes knowledge of the DSEEP, and we will not attempt to cover all of the engineering aspects of distributed simulation. Instead, this document will mirror the steps of the DSEEP and call attention to specific issues and customizations for MSaaS. The DSEEP already has overlays for three simulation enclaves, Distributed Interactive Simulation (DIS), Test and Training Enabling Architecture (TENA), and High Level Architecture (HLA). The MSaaS Reference Architecture introduces a 4th enclave, Industry Standard Service-Oriented Technologies (ISSOT). For MSaaS provider, this document can be used as an ISSOT overlay in developing a composed simulation service.

2.1 STEP 1: DEFINE COMPOSED SIMULATION SERVICE OBJECTIVES

While identifying needs and objectives for a Composed Simulation Services is fundamentally not different from the DSEEP, the MSaaS implementation provides Simulation Scenario Services [2] to support Step 1. Simulation Scenario Services allow customers and user to articulate information about objectives and specifics about the scenario. This data is stored and may be linked to existing services, hardware, and other resources that may be used to support those objectives. Particularly for large scale simulations designed to support a large number of users, a service supporting this step of the DSEEP offers significant potential for capturing better data while reducing the cost of coordination, such as travel.

2.1.1 Activity 1.1: Identify User/Sponsor Needs

This activity is identical to that described in the DSEEP.

2.1.2 Activity 1.2: Develop Objectives

This activity is identical to that described in the DSEEP.

2.1.3 Activity 1.3: Conduct Initial Planning

This activity is identical to that described in the DSEEP.

2.2 STEP 2: PERFORM CONCEPTUAL ANALYSIS

The conceptual analysis step of this overlay captures the implementation independent requirements for the composed simulation service. The analysis in this step begins with an assessment of the real-world domain to be modelled. It then identifies a strategy for a representation of that domain appropriate for the intended use.

2.2.1 Activity 2.1: Develop Scenario

Since the scenario description is independent of the simulation solution architecture, this activity is identical with the DSEEP. However, the simulation customers and users should use the Simulation Scenario Services in the MSaaS implementation, leading to more consistent data capture and better access to scenario development for distributed audiences. It allows these key operational stakeholders to clearly define the scenario in terms of forces, terrain, weather, and actions to be modelled.

2.2.2 Activity 2.2: Develop Conceptual Model

One of the important principles of SOA is the alignment of services with operational processes. Therefore, it is important to capture information about the operational processes so that they can be effectively modelled within services.

One effective way to capture information about simulation conceptual models is *via* the Base Object Model (BOM) Specification [9]. Using this approach, MSaaS customers and users describe an operational process, and MSaaS providers capture the requirements and dynamics of that process using a BOM template. Note that the BOM specification makes use of object- and event-template definitions used in the High Level Architecture (HLA), but it does not require the use of the HLA [10] to implement base-object models. In the MSaaS case, these models may be implemented as services. In the conceptual model definition phase, it is important to capture information about the Model Identification and Conceptual Model Definition elements of the BOM. Understanding patterns of interplay, where simulation entities interact *via* events to update simulation state, will provide simulation designers the conceptual information they need to select or design the participating simulation services.

The patterns of interplay defined in the conceptual model become critically important during Activity 3.2, Design the Composed Simulation Service Environment and Step 4, Develop the Composed Simulation Service Environment. They support the proper selection of services with integration aligned with the operational concepts defined in the conceptual model.

2.2.3 Activity 2.3: Develop Simulation and Service Requirements

In an SOA environment, there are some unique considerations to be implemented in the recommended activities of the DSEEP. In particular, these requirements will support development of realizations of architectural building blocks in the layers of the NATO C3 Taxonomy [11] or NATO MSaaS RA [2]:

- **Define required behaviors of identified entities and required characteristics of identified events.** These requirements can lead to the selection or development of simulation services. In particular, identifying the stateful behavior and the stateless transition functions will allow decoupling of the service components into a combination of reusable transition functions and other stateful components. If this information has been specified using the Base Object Model Specification [9] in Activity 2.2, it can be pulled from there. Chapter 6 of the MSaaS RA prescribes architectural patterns for stateful and stateless services.

- **Define requirements for natural environment representation.** These requirements will lead to the development of synthetic environment services. They may also be met by existing geospatial services from the NATO C3 Taxonomy [11].

- **Define requirements for live, virtual, and constructive simulations.** These requirements will be major drivers for the selection of participating services, to include the participation of DMAO enclaves *via* the use of HLA, DIS, TENA, or ISSOT, potentially driving the composed simulation service to use a multi-architecture structure as described in the DMAO.

- **Define human or hardware in the loop requirements.** The most likely case for hardware in the loop will be for Command and Control (C2) to simulation interfaces. Chapter 6 of the MSaaS RA has an architectural pattern for C2-Simulation interactions. This pattern can be extended for other types of hardware in the loop such as weapons systems providing data to be consumed in the simulation or consuming data from the simulation to support training or testing.

- **Define performance requirements for the simulation environment.** These requirements will support the development of quality of service requirements and realizations of Platform Service Management and Control Services architectural building block of the NATO C3 Taxonomy [11].

- **Define evaluation requirements for the simulation environment.** These requirements will influence the data publication requirements for the participating services. There are several architectural building blocks that can provide evaluation data, to include Simulation Control Services, M&S Services, and Platform Service Management and Control Services.
- **Define time management requirements (real time *vs.* slower or faster than real time).** These requirements will lead to the development of M&S Message-Oriented Middleware Services and M&S Mediation Services [2] that support time coherent exchange of messages between services.
- **Define host computer, networking, and other hardware requirements.** These requirements will lead to the realizations of ABBs of the Infrastructure Services and Communications Services in the NATO C3 Taxonomy [11]. In a cloud environment these will be instantiated as Infrastructure as a Service elements of the SOCCI Framework [8].
- **Define security requirements for hardware, network, data, and software.** These requirements will be supported at several layers of the architecture. For example, the Platform Computer Information Security Services in the Core Services of the NATO C3 Taxonomy [11] will enforce security policies at the platform level. M&S specific security requirements will be realized by Simulation Applications and Modelling Applications in the Consumer Layer and the M&S Security Services in the Quality of Service Layer [2]. MSaaS providers will have to ensure the security requirements of their MSaaS implementation are met by the M&S services they develop.
- **Define output requirements, including requirements for data collection, raw execution data processing, and data analysis.** These requirements will lead to the realization of Simulation Control Services [2]. These services will provide data to the simulation at initialization and retrieve results data upon completion of the simulation. This step facilitates the integration of simulation services with User Applications, Community of Interest (COI) Specific Services, or COI Enabling Services of the NATO C3 Taxonomy [11].
- **Define execution management requirements.** Realizations of Simulation Control Services or M&S Composition Services [2] from the MSaaS implementation will provide execution management for Composed Simulation Services developed within that implementation. MSaaS providers should derive execution management requirements for simulation services from these existing services. Realizations of the Composed Simulation Services are intended to support automatic and dynamic deployment and execution. Therefore, participating M&S Services and Simulation Applications should not require user interaction during deployment. One strategy is to separate the M&S Service or Simulation Application from its user interface and deploy it as a self-contained service.

  Another **execution management** challenge is the configuration and data initialization of services during automatic deployment. MSaaS providers must design services that support automatic data initialization by the Simulation Control Service.
- **Develop simulation environment test criteria.** These test criteria provide inputs for test cases implemented by realizations of the M&S Certification Services architectural building block [2].

2.3 STEP 3: DESIGN COMPOSED SIMULATION SERVICE

This step of the DSEEP maps the conceptual simulation design and requirements from the previous step into a specific set of simulation services to implement those requirements in the composed simulation service. For MSaaS, the output of this step includes robust definitions of service contracts for the participating services.

2.3.1 Activity 3.1: Discover and Select M&S Services

The basic activity to select the participants in the composed simulation service is essentially the same as the DSEEP. However, while the DSEEP identifies a generic set of M&S repositories as the principal source of candidate participants, the MSaaS Engineering Process identifies existing services as the primary source of participants. The MSaaS implementation provides M&S Repository Services and M&S Registry Services [2] to publish information that can be used to discover M&S services for a composed simulation service.

It is also possible that the composed simulation service contains participants from other enclaves, such as HLA, DIS, or TENA. In this case, the enclave of services composed *via* industry standards becomes the Industry Standard Service-Oriented Technology (ISSOT) enclave of a multi-architecture overlay, and the engineering considerations of the DSEEP Multi-Architecture Overlay (DMAO) [6] come into play. The selected services and other member applications must have a mechanism for integration into the multi-architecture. Chapter 3 of the MSaaS RA [2] gives a topology for integrating an ISSOT enclave into the larger architecture, shown here in Figure 2-1.

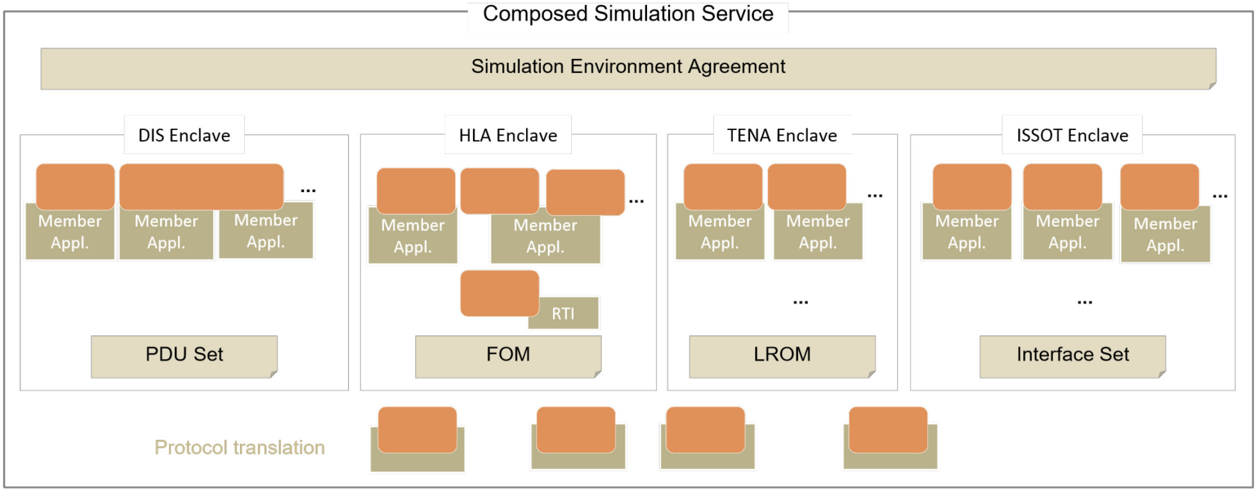

Figure 2-1. ISSOT Enclave as Part of a Composed Simulation Service.

According to the DMAO, maximizing the number of applications that conform to a single architecture reduces the overall technical risk. For a composed simulation service, this suggests selecting MSaaS conformant M&S services wherever possible, minimizing the role of capabilities provided by other enclaves.

The integration of components not designed for M&S, called non-conformant member applications in the DMAO, is easier in some ways for MSaaS. Each non-conformant service will already have an external interface regulated by its service governance policies, described in a service registry, and exposed *via* a service repository. It was designed from the ground up for integration with larger systems. Additional considerations, such as handling of state, must be dealt with. The MSaaS RA [2] gives patterns in Chapter 6 for integrating stateful and stateless services.

It is important to note that, for MSaaS implementations, good decisions depend on good metadata provided *via* the M&S Registry Services, as described in the MSaaS Discovery Service and Metadata document [4]. In addition to technical specifications, such as input and output interface, the service registry should also include important semantic information about the service to support interoperability. A good model for interoperability is the Levels of Conceptual Interoperability Model (LCIM), shown in Table 2-1 [12].

Table 2-1: The Levels of Conceptual Interoperability Model, Along with Technical Specifications, is a Good Model for Interoperability.

LCIM Level	Details Required in Service Description to Achieve the LCIM Level
1	Description of the transport protocol and how to connect to the endpoint.
2	Machine-readable description of the input and output data.
3	Use a commonly understood ontology, or reference model, to describe the meaning of each data input/output element, complete with information about units.
4	Provide information about the dynamic context in which the service is invoked, perhaps described by an activity model or sequence diagram. The Base Object Model [9] template also provides a mechanism for specification of the dynamic context.
5	Provide documentation that develops a clear understanding of what the model's calculations mean in the domain of interest, information about model validation, assumptions under which the model is valid, and limitations of the model.

If dynamic interplay of services was captured *via* the BOM template in Activity 2.2, Develop Conceptual Model, then it can be referenced here to support LCIM 4 interoperability.

2.3.2 Activity 3.2: Design Composed Simulation Service

According to MSaaS Governance Policies [1], an organization will manage existing M&S Services within its MSaaS implementation. A composed simulation service deploys and consumes these M&S services in the overall execution of the simulation. It must introduce strategies to deal with the management of simulation state, the control of simulation events, and the exchange of data between the existing M&S Services. This selection of strategy will influence the development of compliant M&S Services.

M&S Integration Services, which include M&S Mediation Services and M&S Message-Oriented Middleware Services [2], further enable design of the composed simulation service. Realizations of M&S Mediation Services move data between existing services, translating data as necessary between different formats. They can also serve as a gateway to move data between different architectures in a multi-architecture structure. M&S Message-Oriented Middleware Services, enable time-synchronized choreography of simulation services during simulation execution. Finally, the simulation initialization requirements and data input and output requirements provide the necessary information to select or develop the Simulation Control Services [2] that will manage initialization, execution, and data collection for realizations of Composed Simulation Services.

In addition, the composed simulation service may choose to use an existing architecture such as HLA [10] to manage simulation time, state, events, and data exchange. In this case, the DSEEP overlay for the selected architecture should be utilized in conjunction with this ISSOT overlay to design, develop, and execute the simulation solution. Additional guidance for multi-architecture integration can be found in the DSEEP Multi-Architecture Overlay (DMAO) [6].

2.3.3 Activity 3.3: Design M&S Services

For MSaaS, the design of a service can be thought of as the complete specification of the service contract for M&S Services. That service contract will guide the development and implementation of that service, and it will be published as metadata in the M&S Registry Services [2] in accordance with the MSaaS Discovery Service and Metadata specification [4]. Service metadata specifies the data structures used to represent entity parameters, entity state, and event specifications required to represent the conceptual model. It also specifies the API and network-access protocol.

MSaaS providers should also consider design time issues, such as whether to use a stateful or stateless service architectural patterns, level of granularity of individual services, potential for containerization, and the network API, and network access, and security constraints.

2.3.4 Activity 3.4: Prepare Detailed Plan

If Composed Simulation Services are implemented on traditional hardware and networks, such as a lab environment, or a federation of labs, then this step is identical to the steps of the DSEEP. However, a likely technology choice for MSaaS infrastructure will be a cloud environment. If that is the case, considerations of the SOCCI Framework come into play [8]. In the planning phase, designers must consider the pay-for-use cost model of cloud infrastructure in order to properly budget the solution. This often leads to significant savings because resources are only paid for when they are used, with very little idle time.

2.4 STEP 4: DEVELOP COMPOSED SIMULATION SERVICE

During this step of the MSaaS Engineering Process, the design of the composed simulation service and service contracts developed during the previous step will be used to define the information exchanges between services during execution of the simulation. As necessary, member M&S services will be developed or updated to support the composed simulation service. Data access and data storage elements for the Simulation Control Services will be developed to ensure they can support the simulation's data requirements.

2.4.1 Activity 4.1: Develop Simulation Data Exchange Model

The first essential decision during this step is to decide the extent to which the composed simulation service will make use of a common Simulation Data Exchange Model (SDEM). MSaaS providers can take different approaches to the SDEM.

For example, while HLA, TENA, and DIS all prescribe a common SDEM, this is an optional component in a services environment. The MSaaS provider can opt to use a microservices approach, where each service is an independent unit, and not require a common SDEM. The advantage of this approach is that individual microservices do not have to be redesigned every time the data model changes. A more traditional SOA approach does mandate a common SDEM. Advantages of this approach include data consistency, a better understanding of the data entities for all parties, and less reliance on M&S Mediation Services as data is exchanged. A hybrid approach is also possible, where a SDEM is built for the most common and critical set of data exchanges.

Another approach to building the SDEM is to standardize that model not for the entire composed simulation service, but by business process (or operational process) domain. For example, if a composed simulation service includes the effects of sensors, the MSaaS provider could prescribe a common SDEM for the exchange of data by sensors. The BOM Specification suggests a similar approach where the SDEM is built by composing related individual data models into BOM assemblies [9].

In a services environment, there are many technical options to specify the Simulation Data Exchange Model (SDEM). A starting point for this specification is a union of the input and output data from the service contracts specified in Activity 3.3. Other information exchange requirements can come from input and output requirements from Simulation Control Services, Simulation Scenario Services, and M&S Applications. While HLA, TENA, and DIS provide data format specifications for simulation applications, M&S services may make use of any number of data specifications such as XML, JSON, BSON, or Google Protocol Buffers.

The M&S Repository Services in the MSaaS implementation authoritatively stores and manages all SDEMs built for realizations of Composed Simulation Services. This will enable Modelling Applications to query those data models, properly serialize data as it is exchanged, and automatically code generate data interfaces in target languages.

Another consideration is to ensure that the data can be transported properly by M&S Message Oriented Middleware Services. In a SOA environment, heterogeneous data formats are not unusual, so these M&S Message Oriented Middleware Services can be augmented by M&S Mediation Services to translate between data structures or formats. Simulation performance is often a consideration, so development choices should ensure that the simulation solution can scale to portray the entire scenario while still meeting overall performance requirements.

2.4.2 Activity 4.2: Establish Composed Simulation Service Agreements

A detailed guide for establishing federation agreements is given by [13] the Federation Agreements Engineering Template (FEAT). The FEAT gives seven different categories of agreements, which have the following MSaaS considerations:

- **Metadata**. In an MSaaS implementation, many of the agreements between parties are specified in the governance documents, such as those agreements specified in the MSaaS Governance Policies [1]. For services, much of the metadata is stored by the M&S Registry Services, so its metadata specification provides guidance that allows them to publish their metadata and become discoverable. Because of these strong agreements enforced by policies, the metadata in an MSaaS implementation is much richer, allowing for easier discovery, reuse, deployment, composition, and execution of M&S Services.
- **Design.** These agreements capture the design decisions made in the previous step. In an MSaaS implementation, design agreements can take the form of agreeing to use common services for the entire federation, such as a terrain service or combat damage service. Also, service contracts for individual or composed simulation services help formally document design agreements.
- **Execution**. Execution agreements allow M&S Enabling Services to interact with M&S Services, and they can require M&S Services to use specific realizations of these M&S Enabling Services. For example, the service contract of a Simulation Control Service can specify detailed simulation service execution state, messages for initiating the composed simulation service, and for providing input and collecting output data. Therefore, the service contract of a member simulation service can require it to respond to those initialization messages, to consume input data, and to publish output data for consumption by Simulation Control Services.
- **Management**. MSaaS Governance Policies capture a large portion of the agreements needed for management of M&S services. Additional management agreements are needed for the engineering and development of Composed Simulation Services.
- **Data.** If simulation service contracts are developed with a level of detail in accordance with the MSaaS Service Discovery and Metadata specification [4], then these contracts will unambiguously specify the data consumed and produced by a service. The SDEM's stored by the M&S Repository Services further define data agreements between parties.
- **Infrastructure**. For MSaaS, the supporting infrastructure is likely to include a cloud environment. If so, agreements are necessary to ensure all elements of the federation can access the cloud infrastructure. Additional agreements will specify when cloud-based resources are instantiated.
- **Modelling**. For MSaaS, modelling agreements can result in the specification and development of common services used by all members, such as a common damage calculation service. These agreements can also standardize algorithms and output data around key interoperability

considerations, such as coordinate systems and dead reckoning. These agreements can result in the specification and development of M&S Mediation Services to translate multiple data formats to the agreed-upon representation.

A composed simulation service must also implement agreements to coordinate time advance, state management, and event exchange. If the HLA is selected for this purpose, then the HLA Specification provides a framework for federation agreements. Also, M&S Message-Oriented Middleware Services [2] are one way to implement a structure to define management of state, time, and events *via* orchestration.

2.4.3 Activity 4.3: Implement M&S Services

MSaaS providers implementing M&S Services must make implementation technology choices in accordance with the defined conceptual model, the service contract of the individual service, the SDEM, and the agreements of the simulation environment. Then they must ensure the metadata provided by the M&S Registry Services is consistent with their implementation. Finally, they must store their service implementations using the M&S Repository Services so that it can be deployed on demand to MSaaS infrastructure to support testing, initialization, and execution. Modelling Applications and Modelling Services support this step.

2.4.4 Activity 4.4: Deploy to MSaaS Infrastructure

If the MSaaS composed simulation service is implemented on traditional hardware and networks such as a lab environment, or a federation of labs, then this step is identical to the steps of the DSEEP. However, a likely technology choice for MSaaS Infrastructure Services will be a cloud environment. If that is the case, considerations of the SOCCI Framework come into play [8]. In particular, the developers of M&S Services must take into account the characteristics of the cloud provider in order to develop the following capabilities:

- **On-Demand Self-Service.** Develop M&S Composition Services and Simulation Control Services [2] that have the capability to communicate with the cloud service interface in order to automatically provision cloud resources as they orchestrate and start/stop the execution of simulations.
- **Broad Network Access.** Maximize access to services from across the network and using a broad array of devices, such as thick clients, browser-based thin clients, mobile devices, and, if required, command and control systems and hardware in the loop.
- **Resource Pooling.** The MSaaS implementation should support the dynamic assignment of physical and virtual resources on demand to customers executing M&S Services. To support this, MSaaS providers should design services that are independent of the location and specific hardware resources used during this assignment. This capability enables shared use of capacity that often sits idle in data centers and simulation-training centers. The use of container technology is one way to isolate services and their target operating systems to support dynamic resource assignment.
- **Rapid Elasticity.** Platform Service Management and Control Services provide the ability to capture metrics about M&S Services performance and, when needed, enable elastic provisioning of resources allocated to that service in order to meet performance demands. M&S Services should be designed to take advantage of this elastic capability.
- **Measured Service**. The Infrastructure Service Management and Control Services [11] will be able to monitor and control resource usage by M&S services. This data supports pay-per-use scenarios, and it also provides data to support optimization of Composed Simulation Services for the MSaaS infrastructure.

Additional network considerations will complicate MSaaS in a multi-architecture environment. The MSaaS infrastructure must enable communication between the ISSOT enclave, typically a cloud, and elements of the rest of the architecture, which may exist in lab environments, training facilities, or perhaps another cloud. Conflicting policies such as network policies, security policies, or classification policies will have to be resolved to allow the MSaaS infrastructure to integrate with these other architectures. One possibility is to integrate M&S Mediation Services with M&S Security Services that manages information processing in compliance with different security and classification systems.

2.5 STEP 5: PLAN, INTEGRATE, AND TEST COMPOSED SIMULATION SERVICE

In this step, M&S Services are isolated and tested to ensure that they are prepared to execute the Composed Simulation Service.

2.5.1 Activity 5.1: Plan Execution

This activity is identical to that described in the DSEEP.

2.5.2 Activity 5.2: Integrate Composed Simulation Service

If the composed simulation service is implemented on traditional hardware and networks such as a lab environment, or a federation of labs, then this step is identical to the steps of the DSEEP. However, a composed simulation service deployed to a cloud environment brings additional considerations for integration because the cloud infrastructure will have to allocate resources prior to execution. These resources must be provisioned on demand, and services running in virtualized containers must be able to discover each other and integrate prior to execution. The cloud infrastructure provides resources, M&S Certification Services [2] can be run to verify service connectivity and execution. They may also be used for pre-runtime V&V of Simulation Services before these are stored using M&S Repository Services.

2.5.3 Activity 5.3: Test Composed Simulation Service

In an MSaaS implementation, the same three levels of testing are needed as specified in the DSEEP. In simulation service testing, simulation services are tested to ensure they comply with the service contract and with the specifications of the MSaaS Governance Policies [1]. Then integration testing is performed to ensure that the simulation services interact with M&S Enabling Services in accordance with the existing agreements. Finally, in interoperability testing, all simulation services are executed together as managed by the Simulation Control Services, the M&S Composition Services, and the M&S Message Oriented Middleware or M&S Mediation Services. In each testing step, M&S Certification Services can verify that all services are running properly.

In a multi-architecture environment, the above testing ensures that the ISSOT enclave is functioning properly. Additional testing is required in accordance with the DMAO recommendations to ensure that the ISSOT enclave integrates with the other enclaves in the composed simulation service. Multi-architecture testing can be very complex, so disciplined execution of testing at all levels reduces complexity. Services and enclaves should be thoroughly tested at their levels before testing at the multi-architecture level. This simplifies the identification and resolution of errors. In addition, the disciplined development and use of test cases, and M&S Certification Services provides a means for communicating and enforcing policies and agreements.

2.6 STEP 6: EXECUTE COMPOSED SIMULATION SERVICE

In this step, the composed simulation service is executed in the MSaaS infrastructure in pursuit of the objectives for which the simulation has been developed.

2.6.1 Activity 6.1: Execute Composed Simulation Service

In an MSaaS, simulation execution consists of using Simulation Control Services to deploy and execute iterations of the composed simulation service using the MSaaS infrastructure. For automatic execution, the Simulation Control Services instantiates services in the required order while also coordinating the passing of initialization data to these services.

If using cloud infrastructure, scaling can support multiple iterations of the simulation using different inputs or in order to generate sufficient random output for analysis. In a multi-architecture environment, the Simulation Control Services must also integrate with the simulation initialization, execution, and data collection agreements of the larger architecture.

2.6.2 Activity 6.2: Prepare Simulation Outputs

In MSaaS, this step involves retrieving data from M&S Services so that it can be analyzed by specialized services or downloaded for analysis in other tools. The availability of cloud storage capabilities opens up the possibility of storing much more simulation data than is possible in limited infrastructure, so specialized tools or Big Data capabilities may be needed to retrieve outputs. It is also possible that mediation capabilities of the M&S Mediation Services may be used to transform simulation results into formats desirable for output analysis.

2.7 STEP 7: ANALYZE DATA AND EVALUATE RESULTS

2.7.1 Activity 7.1: Analyze Data

This activity is identical to that described in the DSEEP.

2.7.2 Activity 7.2: Evaluate and Feedback Results

The process of analyzing the data from the federation execution and producing the final results is identical to that of the DSEEP. With respect to archiving reusable products, Simulation Services should already be published and documented using the M&S Repository Services in accordance with MSaaS Governance Policies [1]. This enables reuse of those services in other compositions developed for that MSaaS implementation.

Chapter 3 – RECOMMENDATIONS FOR FOLLOW-ON ACTIVITIES

MSG-136 provided a detailed description of a recommended MSaaS Engineering Process to build Composed Simulation Services in the context of MSaaS and the MSaaS Reference Architecture, mirrored after the DSEEP and DMAO. However, MSG-136 did not have time to completely execute this engineering process, neither did it have time to complete the recommended modifications to the DMAO and align these with the engineering process (see Annex A). Also, MSG-136 considered several concepts that did not make it into the final engineering process. Based on this, we provide the following recommendations for follow-on activities:

- Execute this engineering process during the development of Composed Simulation Services and update it based on lessons learned.
- Update service description template in the MSaaS Discovery Service and Metadata document [4] to include machine-readable and human-readable metadata to support composition of services in a dynamic context, as described in the BOM specification.
- Update service description template in the MSaaS Discovery Service and Metadata document [4] to include the storage of SDEM's with the M&S Registry Services.
- Review and update the recommended modifications to the DMAO and align these with the recommended MSaaS Engineering Process.

Chapter 4 – REFERENCES

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Annex A – UPDATES TO DSEEP MULTI-ARCHITECTURE OVERLAY (DMAO)

Annex A provides a provisional list of recommended modifications to the DMAO [6] that MSG-136 identified. These modifications were developed before the description of the MSaaS Engineering Process was available and are, therefore, not aligned with this process. The recommended modifications are highlighted in red. Red strikethrough indicates existing DMAO text to be removed.

Table A-1 provides an overview of the recommendations for DMAO modifications per step and activity:

Table A-1: Recommended Changes to DSEEP Multi-Architecture Overlay (DMAO).

Step	Activity	Recommended DMAO Changes
1. Define simulation environment objectives.	1.1 Identify user/sponsor needs.	*None.*
	1.2 Develop objectives.	*None.*
	1.3 Conduct initial planning.	*None.*
2. Perform conceptual analysis.	2.1 Develop scenario.	*None.*
	2.2 Develop conceptual model.	*None.*
	2.3 Develop simulation environment requirements.	*None.*
3. Design Simulation Environment.	3.1 Select member applications.	Issue 1: Member application selection criteria for multi-architecture simulation environments. • Description: Address the potential use of services. • Action: Cover costs and performance when using services instead of member applications. Issue 2: Non-conforming member applications. • Description: Add SOA to list of architectures. • Action: Add SOA description under 2.iii.
	3.2 Design simulation environment	Issue 8: Multi-architecture and inter-architecture performance. • Description: Add SOA to list of architectures. • Action: None.

Step	Activity	Recommended DMAO Changes
3. Design Simulation Environment (cont'd.)	3.2 Design simulation environment (cont'd).	Issue 13 [new]: SOA interface usage and selection decisions. • Description: Describe latency/performance issues potentially introduced by using a SOA/Web services approach. • Action: Add cost/benefit analysis recommendations for SOA/web services.
	3.3 Design member applications.	*None*
	3.4 Prepare detailed design.	*None*
4. Develop Simulation Environment.	4.1 Develop Simulation Data Exchange Model.	Issue 1: Metamodel incompatibilities. • Description: Add SOA and WSDL/REST APIs to list of considerations. • Action: None.
	4.2 Establish simulation environment agreements.	Issue 2: Tool availability and compatibility. • Description: Add that not all SOAs inherently have an externally defined SDEM except e.g., WSDL in some cases. • Action: None.
	4.3 Implement member application designs.	*None.*
	4.4 Implement simulation environment infrastructure.	*None.*
5. Integrate and Test Simulation Environment.	5.1 Plan execution.	*None.*
	5.2 Integrate simulation environment.	*None.*
	5.3 Test simulation environment.	*None.*
6. Execute Simulation.	6.1 Execute simulation.	*None.*
	6.2 Prepare simulation environment outputs.	*None.*
7. Analyze Data and Evaluate Results.	7.1 Analyze data.	*None.*
	7.2 Evaluate feedback results.	*None.*

A.1 STEP 1: DEFINE SIMULATION ENVIRONMENT OBJECTIVES

No modifications.

A.2 STEP 2: PERFORM CONCEPTUAL ANALYSIS

No modifications.

A.3 STEP 3: DESIGN SIMULATION ENVIRONMENT

A.3.1 Activity 3.1: Select Member Applications

1. Issue 1: Member application selection criteria for multi-architecture simulation environments.

   Description: Address the potential use of services.

   The selection of member applications and services for multi-architecture simulation environments requires additional criteria beyond those used for member application selection decisions in single architecture simulation environments. Some potential member applications or services of a multi-architecture simulation environment may support only one of the architectures being employed while other potential member applications or services support multiple architectures. The selection decision becomes more complex for the system designers because the architecture support capabilities of a potential member application or service should be considered in addition to its simulation representational capabilities. A tradeoff may become necessary between a highly capable member application or service that supports a single architecture and another less capable member application or service that supports multiple architectures. Such tradeoffs are an important part of the selection process and ignoring such considerations may result in schedule slippages and unanticipated technical problems.

   Action: Cover costs and performance when using services instead of member applications.

   The simulation architecture(s) that individual member applications support are perhaps the most obvious additional criteria to consider in selecting member applications for a multi-architecture simulation environment. All else being equal, maximizing the number of member applications using the same architecture reduces integration effort and overall technical risk (e.g., Ref. [1]). The benefit of integrating a member application into a multi-architecture simulation environment should be evaluated with respect to the effort required for the integration. Services may be chosen to provide required functionality. While this may reduce the cost of integration, it may also negatively impact network performance. Given that the need for a multi-architecture environment is determined in Activity 3.1 (select member applications), the assumptions made in Activity 1.3 (conduct initial planning) and Activity 2.3 (develop simulation environment requirements) should be reviewed and adjusted, if necessary.

2. Issue 2: Non-conforming member applications.

   Description: Add SOA to list of architectures

   Some simulation environments may have requirements that motivate the inclusion of models, utilities, servers, or other systems that are not able to interoperate via any of the distributed simulation architectures (such as DIS, HLA, ~~and~~ TENA, and SOA). They may have no external interfaces at all, have external interfaces that are not simulation-oriented (e.g., cellular wireless protocols in portable devices), or have external interfaces designed for purposes other than distributed simulation. Member applications that do not use any distributed simulation architecture will be termed “non-conforming”.

Integrating a non-conforming member application into a simulation environment will require adding an external interface, or adapting its existing external interface, to enable it to interoperate with the other member applications. Of course, this issue exists with a single-architecture simulation environment, but there are additional factors to be considered in the context of a multi-architecture simulation environment.

Action: Add SOA description under 2.iii

SOA relies predominantly on standards defined by the World Wide Web Consortium (W3C), e.g., Web Service Definition Language (WSDL) and Representational State Transfer (REST). While SOA is not a simulation-specific architecture, it is increasingly employed to deliver M&S services.

A.3.2 Activity 3.2: Design Simulation Environment

1. Issue 8: Multi-architecture and inter-architecture performance.

   Description: Add SOA to list of architectures.

   When multiple distributed simulation architectures and member applications developed for multiple architectures are linked into a single simulation environment, performance should be considered. In some (but not all) multi-architecture simulation environments, inter-architecture differences in runtime performance may exist. If present, inter-architecture performance differences may result from the fundamental design assumptions of the distributed simulation architectures or the implementations of the architectures' supporting software (e.g., HLA RTI, TENA middleware, SOA). Performance issues may also arise from the technical solutions used to link the components of the multi-architecture simulation environment (e.g., gateways) and the implementations of the member applications. For some simulation environments and some applications, performance differences significant enough to affect the utility of the multi-architecture simulation environment are possible.

   Action: None.

2. Issue 13: SOA interface usage and selection decisions [new]

   Description: Describe latency/performance issues potentially introduced by using a SOA/Web services approach.

   When an SOA is employed to deliver M&S services, the physical location of the service, and consequently potential latency and performance impacts of integrating it into the simulation environment, may not be known *a priori*.

   Action: Add cost/benefit analysis recommendations for SOA/Web services.

   Prior to selecting a specific service:

   - Review its Service Level Agreements (SLAs);
   - Consider identifying another similar service known to provide better performance;
   - Perform preliminary performance tests to determine suitability; and
   - Determine whether the benefits of reusing an existing service outweigh the potential performance impacts.

A.4 STEP 4: DEVELOP SIMULATION ENVIRONMENT

A.4.1 Activity 4.1: Develop Simulation Data Exchange Model

1. Issue 1: Metamodel incompatibilities

   Description: Add SOA and WSDL/REST APIs to list of considerations.

   Differences in the underlying data exchange model structures used by the various architectures can cause incompatibilities in a multi-architecture simulation environment. Specifically, the set of data fields that compose an HLA FOM (as specified in the HLA Object Model Template (OMT)), the set of fields that compose a TENA Logical Range Object Model (LROM) (as specified in the TENA metamodel), the set of fields that define DIS PDU structures are not the same. These sets of data fields and their relationships define the architectures' metamodels.

   Action: None.

A.4.2 Activity 4.2: Establish Simulation Environment Agreements

2. Issue 2: Tool availability and compatibility

   Description: Add that not all SOAs inherently have an externally defined SDEM except e.g., WSDL in some cases.

   From the earliest distributed simulation environment implementation projects, developers have created and used software tools to support their efforts. (It is important to distinguish "tools," which actively perform or assist developers in performing some implementation task, such as an SDEM editor, from "processes," which passively provide guidance to developers on the tasks and task sequence to be performed, such as this document.) Tools are available for almost every activity in the implementation process, including those that occur before, during, and after simulation environment execution. However, nearly all of those tools are intentionally or effectively architecture specific, either performing a task unique to one architecture or performing an architecture-generic task in a way specific to one architecture. For an example of the latter, all of the architectures under discussion (DIS, HLA, and TENA) have SDEMs, but an SDEM editor that works only with SDEMs structured according to the OMT is effectively HLA specific. And not all SOAs inherently have an externally defined SDEM except e.g., WSDL, in some cases.

   Action: None.

A.5 STEP 5: INTEGRATE AND REST SIMULATION ENVIRONMENT

No modifications.

A.6 STEP 6: EXECUTE SIMULATION

No modifications.

A.7 STEP 7: ANALYZE DATA AND EVALUATE RESULTS

No modifications.

A.8 REFERENCES

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14. Abstract

M&S as a Service (MSaaS) is a concept that combines service orientation and the provision of M&S applications via the as-a-service model of cloud computing to enable more composable simulation environments that can be deployed and executed on-demand. NATO MSG-136 investigated the concept of MSaaS and provided technical and organizational foundations to establish the Allied Framework for M&S as a Service within NATO and partner nations. The Allied Framework for M&S as a Service is the common approach of NATO and nations towards implementing MSaaS and is defined by the Operational Concept Document, Technical Reference Architecture, and MSaaS Governance Policies.

This document describes the MSaaS Engineering Process to be executed for building a Composed Simulation Service within the Allied Framework for MSaaS or compliant national MSaaS implementations. It mirrors the structure of the Distributed Simulation Engineering and Execution Process (DSEEP) and provides guidance specific to developing M&S Services and MSaaS environments.

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