NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(MSG-136)TP/831

www.sto.nato.int

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

Modelling and Simulation as a Service, Volume 1: MSaaS Technical Reference Architecture

(La modélisation et simulation en tant que service, Volume 1 : Architecture de référence technique)

Developed by NATO MSG-136.

Published May 2019

Distribution and Availability on Back Cover

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(MSG-136)TP/831

www.sto.nato.int

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

Modelling and Simulation as a Service, Volume 1: MSaaS Technical Reference Architecture

(La modélisation et simulation en tant que service, Volume 1: Architecture de référence technique)

Developed by NATO MSG-136.

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.

The content of this publication has been reproduced directly from material supplied by STO or the authors.

Published May 2019

ISBN 978-92-837-2157-4

Table of Contents

		Page
List of Figures		**vi**
List of Tables		**vii**
List of Acronyms		**viii**
Nomenclature		**ix**
Conventions		**xi**
MSG-136 Membership List		**xii**
Executive Summary and Synthèse		**ES-1**
Chapter 1 – Introduction		**1-1**
1.1	Background	1-1
1.2	Intended Use	1-1
1.3	Overview of the MSaaS Reference Architecture	1-3
1.4	Document Overview	1-3
Chapter 2 – Principles		**2-1**
Chapter 3 – Architecture Concepts		**3-1**
3.1	Overview	3-1
3.2	MSaaS Architecture Framework	3-2
3.2.1	Architecture Ontology: The Open Group SOA Reference Architecture	3-2
3.2.2	Overarching Architecture: The C3 Taxonomy	3-4
3.2.3	Topology: Composed Simulation Services	3-7
3.2.4	Scope of the MSaaS Reference Architecture	3-9
Chapter 4 – MSaaS Reference Architecture Structure		**4-1**
4.1	Overview	4-1
4.2	Description of Layers	4-2
4.2.1	Layer 1: Operational Systems Layer	4-2
4.2.2	Layer 2: Service Components Layer	4-2
4.2.3	Layer 3: Services Layer	4-3
4.2.4	Layer 4: Business Process Layer	4-3
4.2.5	Layer 5: Consumer Layer	4-3
4.2.6	Layer 6: Integration Layer	4-4
4.2.7	Layer 7: Quality of Service Layer	4-4
4.2.8	Layer 8: Information Layer	4-5
4.2.9	Layer 9: Governance Layer	4-5

Chapter 5 – Architecture Building Blocks **5-1**
5.1 Overview 5-1
5.2 M&S Enabling Services 5-4
5.2.1 M&S Integration Services 5-5
5.2.1.1 M&S Mediation Services 5-5
5.2.1.2 M&S Message-Oriented Middleware Services 5-6
5.2.2 M&S Composition Services 5-9
5.2.3 Simulation Control Services 5-11
5.2.4 Simulation Scenario Services 5-13
5.2.5 M&S Information Services 5-14
5.2.5.1 M&S Repository Services 5-15
5.2.5.2 M&S Registry Services 5-15
5.2.6 M&S Security Services 5-16
5.2.7 M&S Certification Services 5-17
5.3 M&S Services 5-18
5.3.1 Simulation Services 5-19
5.3.2 Modelling Services 5-21
5.3.3 Composed Simulation Services 5-22
5.4 M&S User Applications 5-22
5.4.1 Simulation Applications 5-22
5.4.2 Modelling Applications 5-23

Chapter 6 – Architecture Patterns **6-1**
6.1 Overview 6-1
6.2 M&S Enabling Services Patterns 6-2
6.2.1 Composition Pattern 6-2
6.2.1.1 Problem Description 6-2
6.2.1.2 Solution Description 6-2
6.2.1.3 Illustrations 6-2
6.2.2 C2-Simulation Pattern 6-2
6.2.2.1 Problem Description 6-2
6.2.2.2 Solution Description 6-2
6.2.2.3 Illustrations 6-2
6.2.3 Distributed State Data Pattern 6-4
6.2.3.1 Problem Description 6-4
6.2.3.2 Solution Description 6-4
6.2.3.3 Illustrations 6-4
6.2.3.4 Other Information 6-5
6.3 M&S Services Patterns 6-5
6.3.1 Stateful Pattern 6-5
6.3.1.1 Problem Description 6-5
6.3.1.2 Solution Description 6-5
6.3.1.3 Illustrations 6-5
6.3.1.4 Other Information 6-5
6.3.2 Stateless Pattern 6-7

6.3.2.1 Problem Description 6-7
6.3.2.2 Solution Description 6-7
6.3.2.3 Illustrations 6-7
6.3.2.4 Other Information 6-7
6.3.3 Shared Environment Models Pattern 6-7
6.3.3.1 Problem Description 6-7
6.3.3.2 Solution Description 6-8
6.3.3.3 Illustrations 6-8
6.3.4 Shared Computational Effects Models 6-8
6.3.4.1 Problem Description 6-8
6.3.4.2 Solution Description 6-8
6.3.4.3 Illustrations 6-8
6.3.5 Shared Presentation of Models 6-8
6.3.5.1 Problem Description 6-8
6.3.5.2 Solution Description 6-10
6.3.5.3 Illustrations 6-10
6.3.6 Other COI Service Pattern 6-10
6.3.6.1 Problem Description 6-10
6.3.6.2 Solution Description 6-10
6.3.6.3 Illustrations 6-11

Chapter 7 – Summary and Conclusions 7-1
7.1 Summary 7-1
7.2 Recommendation 7-1
7.3 Conclusion 7-2

Chapter 8 – References 8-1

Annex A – Traceability with NATO C3 Taxonomy A-1
A.1 NATO C3 Taxonomy – MSaaS RA ABB A-1
A.1.1 Back-End Capabilities > Technical Services > COI Services A-1
A.1.2 User-Facing Capabilities A-1
A.2 MSaaS RA ABB – NATO C3 Taxonomy A-1
A.2.1 COI Enabling Services A-1
A.2.2 COI Specific Services A-2
A.2.3 M&S User Applications A-2

Annex B – NATO C3 Taxonomy B-1
B.1 C3 Taxonomy B-1
B.2 User Applications B-2
B.3 Technical Services B-4

List of Figures

Figure		Page
Figure 1-1	Allied Framework for MSaaS – from Operational Concept Document	1-2
Figure 3-1	MSaaS Architecture Framework	3-1
Figure 3-2	Architecture Ontology	3-3
Figure 3-3	C3 Taxonomy – Top-Level View	3-5
Figure 3-4	C3 Taxonomy (Detail of CIS Capabilities)	3-6
Figure 3-5	The NATO C3 Taxonomy as a Dynamic Library for the MSaaS RA	3-7
Figure 3-6	Composed Simulation Service	3-8
Figure 3-7	Simulation Environment; Concrete Implementations in Olive	3-8
Figure 3-8	Boundary of Composed Simulation Service and Scope of MSaaS RA	3-9
Figure 4-1	MSaaS RA Layers	4-2
Figure 5-1	MSaaS RA NATO C3 Taxonomy Extensions	5-2
Figure 5-2	M&S User Applications Hierarchy	5-3
Figure 5-3	M&S Enabling Services Hierarchy	5-3
Figure 5-4	M&S Services Hierarchy	5-4
Figure 6-1	Composition Pattern	6-3
Figure 6-2	C2-Simulation Pattern	6-3
Figure 6-3	Distributed State Data Pattern	6-4
Figure 6-4	Message-Oriented Middleware	6-4
Figure 6-5	Stateful Service Pattern	6-6
Figure 6-6	Stateful Service State Transition Diagram	6-6
Figure 6-7	Stateless Service Pattern	6-7
Figure 6-8	Synthetic Environment Services Pattern	6-9
Figure 6-9	Computational Effects Services Pattern	6-9
Figure 6-10	Presentation Pattern	6-10
Figure 6-11	Other COI Services Pattern	6-11
Figure B-1	NATO C3 Taxonomy Overview	B-1

List of Tables

Table		Page
Table 4-1	Layers and Architecture Building Blocks	4-1
Table B-1	Overview of User Applications	B-2
Table B-2	Overview of Technical Services	B-4

List of Acronyms

ABB	Architecture Building Block
AMSP	Allied Modelling and Simulation Publication
AP	Architecture Pattern
C2	Command and Control
C2IS	C2 Information System
C3	Consultation, Command, and Control
COI	Community of Interest
CRUD	Create, Read, Update and Delete
DIS	Distributed Interactive Simulation
DMAO	DSEEP Multi-Architecture Overlay
DSEEP	Distributed Simulation Engineering and Execution Process
FEAT	Federation Engineering Agreements Template
FOM	Federation Object Model
HLA	High Level Architecture
IDE	Integrated Development Environment
ISSOT	Industry Standard Service-Oriented Technology
JISR	Joint Intelligence, Surveillance and Reconnaissance
LROM	Logical Range Object Model
M&S	Modelling and Simulation
MOM	Message-Oriented Middleware
MSaaS	M&S as a Service
NAF	NATO Architecture Framework
QoS	Quality of Service
RA	Reference Architecture
SDEM	Simulation Data Exchange Model
SMC	Service Management and Control
SOA	Service-Oriented Architecture
STANAG	Standardization Agreement
TENA	Test and Training Enabling Architecture
TOGAF	The Open Group Architecture Framework

Nomenclature

Architecture Building Block	Represents a component of the reference architecture and describes a logical aspect of the overall architecture.
Capability	An ability that an organization, person, or system possesses to deliver a product or service. A capability represents a requirement or category of requirements. See Ref. [1]
Choreography	A service composition where the elements in the composition interact in a non-directed fashion, yet with each autonomous member knowing and following a predefined pattern of behavior for the entire composition. See Ref. [2].
Enabling Technology	A technical realization or instance of an ABB. See Ref. [1]. For example, HLA-RTI for M&S Message Oriented Middleware.
Layer	An abstraction of a grouping of a cohesive set of architecture building blocks that support a set of related capabilities.
Pattern	Fundamental structural organization schema for a system; a pattern provides a set of predefined subsystems, specifies their responsibilities, and includes rules and guidelines for organizing the relationships between them.
Principles	Rules and guidelines for the reference architecture.
Orchestration	A service composition where one particular element used by the composition oversees and directs the other elements. The element that directs an orchestration is, by definition, different than the orchestration itself. See Ref [2].
Reference Architecture	An abstract form of architecture. A reference architecture generally provides a template solution for a concrete solution architecture. See Ref. [3], architecture types (Reference Architecture).
Registry	A generic storage providing the ability to store, manage and retrieve references to authoritative information.
Repository	A generic storage providing the ability to store assets and search for an asset by different perspectives such as for general description, classification, usage, and content. See Ref. [1], Governance Layer.
Service	A service is a logical representation of a repeatable activity that has a specified outcome. It is self-contained and is a 'black box' to its consumers. See Ref. [4], Service Class.
Service Composition	A service composition is the result of assembling a collection of services (see Ref. [2]), for the purpose of the simulation environment.
Service-Oriented Architecture	Service-Oriented Architecture (SOA) is an architectural style that supports service-orientation. See Ref. [4], Overview.
Simulation Resource	Any M&S-related resource (e.g., terrain data, simulation system, 3-D model).

Solution Architecture	The architecture of a specific solution, derived from the reference architecture. See Ref. [3], architecture types (Target Architecture).
Solution Implementation	The implementation of the solution architecture.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 and summarized below. See Ref. [5].

MUST	This word, or the terms "REQUIRED" or "SHALL", mean that the definition is an absolute requirement of the specification.
MUST NOT	This phrase, or the phrase "SHALL NOT", mean that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the adjective "RECOMMENDED", mean that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" mean that there may exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the adjective "OPTIONAL", mean that an item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because the vendor feels that it enhances the product while another vendor may omit the same item. An implementation which does not include a particular option MUST be prepared to interoperate with another implementation which does include the option, though perhaps with reduced functionality. In the same vein, an implementation which does include a particular option MUST be prepared to interoperate with another implementation which does not include the option (except, of course, for the feature the option provides).

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.

MSG-136 Membership List

CO-CHAIRS

Dr. Robert SIEGFRIED
aditerna GmbH
GERMANY
Email: robert.siegfried@aditerna.de

Mr. Tom VAN DEN BERG
TNO Defence, Security and Safety
NETHERLANDS
Email: tom.vandenberg@tno.nl

MEMBERS

LtCdr Tevfik ALTINALEV
Turkish Navy
TURKEY
Email: taltinalev@hotmail.com

Mr. Gultekin ARABACI
NATO JFTC
POLAND
Email: gultekin.arabaci@jftc.nato.int

Mr. Anthony ARNAULT
ONERA
FRANCE
Email: anthony.arnault@onera.fr

Col Thierry BELLOEIL
NATO ACT
UNITED STATES
Email: thierry.belloeil@act.nato.int

Dr. Michael BERTSCHIK
DEU Bundeswehr
GERMANY
Email: MichaelBertschik@bundeswehr.org

LtCol Dr. Marco BIAGINI
NATO M&S Centre of Excellence
ITALY
Email: mscoe.cde01@smd.difesa.it

Mr. Maxwell BRITTON
Department of Defence
AUSTRALIA
Email: maxwell.britton1@defence.gov.au

Dr. Solveig BRUVOLL
Norwegian Defence Research Establishment
NORWAY
Email: solveig.bruvoll@ffi.no

Dr. Pilar CAAMANO SOBRINO
CMRE
ITALY
Email: Pilar.Caamano@cmre.nato.int

Prof. Dr. Erdal CAYIRCI
Research Center for STEAM
TURKEY
Email: erdal@dataunitor.com

Mr. Turgay CELIK
MILSOFT Software Technologies
TURKEY
Email: tcelik@milsoft.com.tr

LtCol Roberto CENSORI
NATO M&S CoE
ITALY
Email: mscoe.ms08@smd.difesa.it

Maj Fabio CORONA
NATO M&S Centre of Excellence
ITALY
Email: mscoe.cde04@smd.difesa.it

Dr. Anthony CRAMP
Department of Defence
AUSTRALIA
Email: anthony.cramp@dst.defence.gov.au

Mr. Raphael CUISINIER
ONERA
FRANCE
Email: raphael.cuisinier@onera.fr

Mr. Efthimios (Mike) DOUKLIAS
Space and Naval Warfare Systems Center Pacific
UNITED STATES
Email: mike.d.douklias@navy.mil

Ing Christian FAILLACE
LEONARDO S.p.a.
ITALY
Email: christian.faillace@leonardocompany.com

Dr. Keith FORD
Thales
UNITED KINGDOM
Email: keith.ford@uk.thalesgroup.com

LtCol Stefano GIACOMOZZI
General Defence Staff
ITALY
Email: mscoe.ds02@smd.difesa.it

Mr. Sabas GONZALEZ GODOY
NATO ACT
UNITED STATES
Email: Sabas.Gonzalez@act.nato.int

Ms. Amy GROM
Joint Staff J7
UNITED STATES
Email: amy.m.grom.civ@mail.mil

Mr. Yannick GUILLEMER
French MoD
FRANCE
Email: yannick.guillemer@intradef.gouv.fr

Dr. Jo HANNAY
Norwegian Defence Research Establishment (FFI)
NORWAY
Email: jo.hannay@ffi.no

Mr. Andrew HOOPER
MOD
UNITED KINGDOM
Email: andy.hooper321@mod.uk

Mr. Willem (Wim) HUISKAMP
TNO Defence, Security and Safety
NETHERLANDS
Email: wim.huiskamp@tno.nl

Dr. Frank-T. JOHNSEN
Norwegian Defence Research Establishment (FFI)
NORWAY
Email: frank-trethan.johnsen@ffi.no

LtCol Jason JONES
NATO M&S CoE
ITALY
Email: mscoe.dr02@smd.difesa.it

Lt Angelo KAIJSER
Dutch Ministry of Defence
NETHERLANDS
Email: AJ.Kaijser@mindef.nl

Mr. Daniel KALLFASS
EADS Deutschland GmbH/CASSIDIAN
GERMANY
Email: daniel.kallfass@airbus.com

Col Robert KEWLEY
West Point
UNITED STATES
Email: Robert.Kewley@usma.edu

LtCol Gerard KONIJN
Dutch Ministry of Defence
NETHERLANDS
Email: gerard.konijn@gmail.com

Mr. Niels KRARUP-HANSEN
MoD DALO
DENMARK
Email: nkh@mil.dk

Mr. Vegard Berg KVERNELV
Norwegian Defence Research Establishment (FFI)
NORWAY
Email: vegard.kvernelv@ffi.no

Capt Peter LINDSKOG
Swedish Armed Forces
SWEDEN
Email: peter.j.lindskog@mil.se

Mr. Jonathan LLOYD
Defence Science and Technology Laboratory (Dstl)
UNITED KINGDOM
Email: jplloyd1@dstl.gov.uk

Mr. Jose-Maria LOPEZ RODRIGUEZ
Nextel Aerospace, Defence and Security (NADS)
SPAIN
Email: jmlopez@nads.es

Mr. Rene MADSEN
IFAD TS A/S
DENMARK
Email: Rene.Madsen@ifad.dk

Ms. Sylvie MARTEL
NCIA
NETHERLANDS
Email: Sylvie.Martel@ncia.nato.int

Mr. Gregg MARTIN
Joint Staff J7
UNITED STATES
Email: gregg.w.martin.civ@mail.mil

Mr. Jose Ramon MARTINEZ SALIO
Nextel Aerospace, Defence and Security (NADS)
SPAIN
Email: jrmartinez@nads.es

LtCdr Mehmet Gokhan METIN
Navy Research Centre
TURKEY
Email: m_gokhan_metin@yahoo.com

Mr. Aljosa MILJAVEC
MoD, Slovenian Armed Forces
SLOVENIA
Email: Aljosa.Miljavec@mors.si

Mr. Brian MILLER
U.S. Army
UNITED STATES
Email: brian.s.miller116.civ@mail.mil

Dr. Katherine MORSE
John Hopkins University/APL
UNITED STATES
Email: Katherine.Morse@jhuapl.edu

LtCol Ales MYNARIK
NATO JCBRN Defence COE
CZECH REPUBLIC
Email: mynarika@jcbrncoe.cz

Mr. Rick NEWELL
JFTC
POLAND
Email: rick.newell@jftc.nato.int

Mr. Jeppe NYLOKKE
IFAD TS A/S
DENMARK
Email: jeppe.nylokke@ifad.dk

Mr. Robbie PHILIPPS
Lockheed Martin Corporation
AUSTRALIA
Email: robbie.phillips@lmco.com

Mr. Marco PICOLLO
Finmecanica
ITALY
Email: marco.picollo@finmeccanica.com

Dr. LtCol (Ret) Dalibor PROCHAZKA
University of Defence
CZECH REPUBLIC
Email: dalibor.prochazka@unob.cz

Mr. Tomasz ROGULA
NATO Joint Force Training Centre
POLAND
Email: tomasz.rogula@jftc.nato.int

Dr. Martin ROTHER
IABG mbH
GERMANY
Email: rother@iabg.de

Mr. Angel SAN JOSE MARTIN
NATO ACT
UNITED STATES
Email: Angel.SanJoseMartin@act.nato.int

Maj Alfio SCACCIANOCE
NATO M&S CoE
ITALY
Email: mscoe.cde05@smd.difesa.it

LtCol Wolfhard SCHMIDT
JFTC
POLAND
Email: wolfhard.schmidt@jftc.nato.int

Mr. Barry SIEGEL
SPAWAR Systems Center – Pacific
UNITED STATES
Email: Barry.Siegel@navy.mil

Mrs. Louise SIMPSON
Thales
UNITED KINGDOM
Email: louise.simpson@uk.thalesgroup.com

Mr. Neil SMITH
UK MoD Dstl
UNITED KINGDOM
Email: nsmith@dstl.gov.uk

Mr. Per-Philip SOLLIN
Pitch Technologies AB
SWEDEN
Email: per-philip.sollin@pitch.se

Dr. Ralf STÜBER
CPA ReDev mbH
GERMANY
Email: stueber@supportgis.de

Capt Colin TIMMONS
Department of National Defence
CANADA
Email: colin.timmons@forces.gc.ca

Maj Dennis VAN DEN ENDE
Ministry of Defence
NETHERLANDS
Email: d.vd.ende@mindef.nl

Mr. Martin Dalgaard VILLUMSEN
IFAD TS A/S
DENMARK
Email: Martin.Villumsen@ifad.dk

Mr. Brian WARDMAN
Dstl Portsdown West
UNITED KINGDOM
Email: bwardman@dstl.gov.uk

Mr. Andrzej WNUK
Joint Warfare Centre
NORWAY
Email: andrzej.wnuk@jwc.nato.int

ADDITIONAL CONTRIBUTORS

Mr. Andy BOWERS
US Joint Staff J7
UNITED STATES
Email: francis.bowers@gdit.com

Mr. Brent MORROW
US Military Academy
UNITED STATES
Email: Brent.Morrow@usma.edu

Mr. Cory SAYLES
Lockheed Martin
UNITED STATES
Email: Cory.d.sayles@lmco.com

Mr. Roy SCRUDDER
The University of Texas at Austin
UNITED STATES
Email: roy.scrudder@arlut.utexas.edu

Mr. Dennis WILDE
European IAD Centre
UNITED STATES
Email: dennis.wilde@us.af.mil

Modelling and Simulation as a Service, Volume 1: MSaaS Technical Reference Architecture

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

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 utilise 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 – 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 & Technology efforts to close current gaps.

This document provides the Allied Framework for Modelling and Simulation as a Service (MSaaS) Technical Reference Architecture. The aim of this document is to provide technical guidelines, recommended standards, architecture building blocks and architecture patterns that should be considered in realizing MSaaS capabilities. The Technical Reference Architecture uses the NATO C3 Classification Taxonomy as a tool for describing capability concepts and as a repository for architecture building blocks and patterns.

The main recommendation regarding the Technical Reference Architecture is that NMSG MS3 shall be the custodian of the MSaaS Technical Reference Architecture and implementation recommendations.

La modélisation et simulation en tant que service, Volume 1 : Architecture de référence technique

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

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 l'architecture de référence technique du cadre allié de modélisation et simulation en tant que service (MSaaS). Le but de ce document est de fournir des lignes directrices techniques, des normes

recommandées et des modules et schémas d'architecture qui devraient être pris en considération pendant la réalisation des capacités de MSaaS. L'architecture de référence technique utilise la taxonomie de classification C3 de l'OTAN comme outil de description des concepts de capacité et comme référentiel de modules et de schémas.

La principale recommandation concernant l'architecture de référence technique est que le MS3 du NMSG soit le gardien de l'architecture de référence technique et des recommandations de mise en œuvre de la MSaaS.

Chapter 1 – INTRODUCTION

1.1 BACKGROUND

NATO and the nations use distributed simulation environments for various purposes, such as training, mission rehearsal, or decision support in acquisition processes. Achieving interoperability between participating simulation systems and ensuring credibility of results still requires enormous effort with regards to time, personnel, and budget.

Recent technical developments in the area of cloud computing technology and Service-Oriented Architectures (SOA) offer opportunities to better utilize M&S capabilities to satisfy NATO critical needs. A new concept that includes service orientation and the provision of M&S applications and systems via as a service cloud computing may enable more composable simulation environments that can also be deployed more rapidly and on-demand. This new concept is known as *M&S as a Service* (MSaaS).

NATO MSG-136 ("Modelling and Simulation as a Service – Rapid deployment of interoperable and credible simulation environments") investigates this new concept with the aim to provide the technical and organizational foundations for a future permanent service-based M&S Ecosystem within NATO and partner nations.

MSG-136 focuses on several areas of M&S as a Service within NATO:

- **Governance Concept:** The governance concept and roadmap for M&S as a Service within NATO;
- **Operational Concept:** The operational concept of M&S as a Service, i.e., how does it work from the user point of view; and
- **Technical Concept:** The technical concept of M&S as a Service, providing a technical reference architecture for MSaaS solutions.

This document concerns the technical concept.

1.2 INTENDED USE

This document presents an MSaaS Reference Architecture (RA). The intended users of the MSaaS RA are the technical stakeholders of the Allied Framework for MSaaS; in other words (see Figure 1-1):

- Suppliers/Providers of services and front-ends to be shared in the framework; and
- Simulation Operators who discover, compose and execute services.

The Suppliers/Providers are enterprise and solution architects, systems designers and developers who wish to:

- Develop simulation functionality to be offered through back-end Simulation Services or compositions of Simulation Services offered through back-end Composed Simulation Services;
- Develop front-end functionality to be offered through loosely coupled, light-weight (including web-based and mobile device-based) Simulation Applications (Apps) which can be combined to give users access to Simulation Services and Composed Simulation Services from operational systems or simulation front-ends;
- Develop Framework functionality offered through back-end Modelling Services that support the MSaaS Portal's Discover, Compose and Execute activities;

- Develop front-end functionality to be offered through loosely coupled, light-weight Modelling Applications (Apps) which can be combined into front-ends of the *MSaaS Portal* to give users access to Modelling Services; and
- Share Services and Applications by deploying their metadata using the M&S Repository Services and by deploying their implementation binding information using the M&S Registry Services.

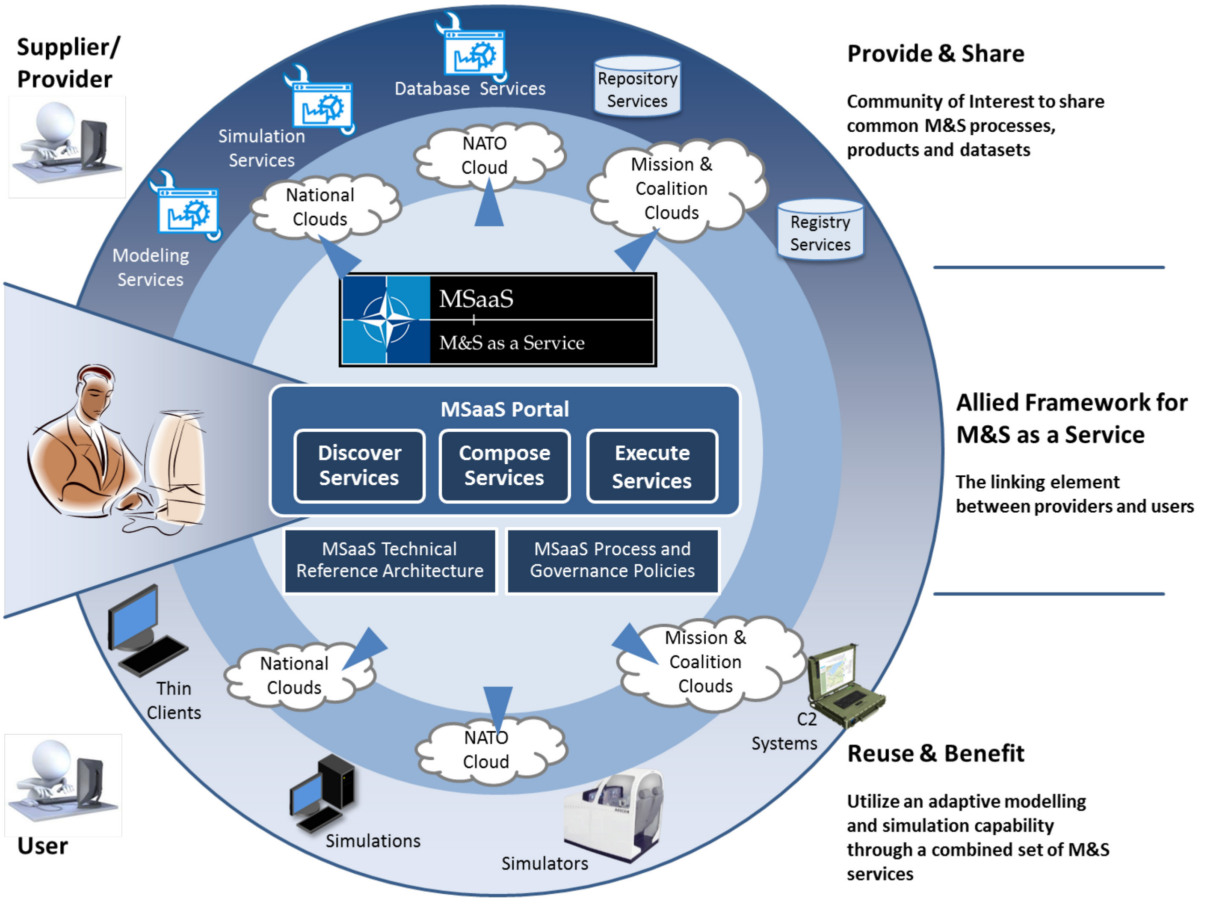

Figure 1-1: Allied Framework for MSaaS – from Operational Concept Document. Ref. 6.

Simulation Operators are semi-technical personnel who wish to discover, compose and execute Simulation Services and Composed Simulation Services for the Operational End-Users by using the MSaaS Portal. In the future, it is envisioned that higher levels of interoperability will allow automatic discovery, composition and execution to larger extents, so that Simulation Operators may, in time, be non-technical operational personnel.

As is apparent from the above, both Suppliers/Providers and Simulation Operators compose simulations from Simulation Services. At present, Simulation Operators might hand over their compositions to the Suppliers who will form the composition as a *simulation as a service*. In the future, Simulation Operators and even operational personnel might be able to do this without the aid of technical personnel.

The MSaaS RA gives implementation-independent blueprints for developing and using the Allied Framework for MSaaS M&S capabilities; i.e. its services and applications as described above. In the next section, we will introduce architecture concepts necessary for defining the reference architecture.

1.3 OVERVIEW OF THE MSAAS REFERENCE ARCHITECTURE

To support the intended technical stakeholders of the Allied Framework for MSaaS, the MSaaS RA provides high-level requirements for the framework's services and user applications in the form of so-called Architecture Building Blocks (ABBs) and high-level patterns, so-called Architecture Patterns (APs), to show how to put together ABBs.

The MSaaS RA will evolve over time as the demands for simulation services, simulation environments and process support evolves. This document therefore presents the MSaaS RA in the form of a framework to be filled out over time. Specifically, the RA consists of two parts:

- A layered *structure* for characterizing the MSaaS RA as a SOA.
- A dynamic library of relevant ABBs and AP to be linked in as the RA's *content*.

The structure is static, while the content constitutes the evolving part.

The MSaaS RA inherits its structure from The Open Group SOA Reference Architecture [1]. The MSaaS RA content is supplied via the NATO C3 Taxonomy [7].

In general, the MSaaS RA should help to answer the following questions:

- What aspects, building blocks, and layers of the MSaaS RA need to be considered in designing and implementing MSaaS solutions, establishing guidelines, or assessing an architecture based on service-oriented principles?
- What building blocks need to be included in each layer of a solution or need to be standardized?
- What are some of the key architectural decisions that need to be made when designing a solution, or assessing an architecture that is based on service-oriented principles?

1.4 DOCUMENT OVERVIEW

The rest of this document presents the MSaaS RA:

- Chapter 2 provides the key principles for the MSaaS RA. The principles are a set of guidelines for the MSaaS RA.
- Chapter 3 explains several architecture concepts that are used in describing the MSaaS RA, such as "Reference Architecture", "Layer", "Architecture Building Block", and "Pattern".
- Chapter 4 gives the structure of the MSaaS RA. The MSaaS RA uses the Open Group SOA Reference Architecture layering, and this chapter provides a mapping of layers to Architecture Building Blocks from the C3 Taxonomy, and to M&S Enabling Services and M&S Services identified for M&S. The mapping is generic in some places and more specific where it concerns M&S.
- Chapter 5 discusses the Architecture Building Blocks, specifying details such as their capability, a description, requirements, and examples. Only ABBs with an M&S focus are discussed in this chapter, while the reader is referred to the NATO C3 Taxonomy for the non-M&S specific ABBs.
- Chapter 6 provides a number of examples of architecture patterns. The purpose of the architecture patterns is to show how ABBs in the MSaaS RA may be combined, how ABBs interact with each other, and what information is generally exchanged between ABBs.
- And finally, Chapter 8 provides the list of references.

The annexes are as follows:

- Annex A provides a traceability between the NATO C3 Taxonomy categories and the MSaaS RA ABBs.
- Annex B provides a summary of the User Applications and Technical Services of the NATO C3 Taxonomy.

Chapter 2 – PRINCIPLES

The MSaaS RA has been defined with the following principles in mind, similar to the Open Group SOA Reference Architecture key principles:

1) The MSaaS RA should be a generic solution that is vendor-neutral.

2) The MSaaS RA should be modular, consisting of building blocks which may be separated and recombined.

3) The MSaaS RA should be extendable, allowing the addition of more specific capabilities, building blocks, and other attributes.

4) The MSaaS RA must be compliant with NATO policies and NATO standards (such as AMSP-01, Ref. [8] and STANAG 4603, Ref. [9].

5) The MSaaS RA must facilitate integration with existing M&S systems.

6) The MSaaS RA should be capable of being instantiated to produce:

   a) Intermediary (domain) architectures; and

   b) Solution architectures.

7) The MSaaS RA should address multiple stakeholder perspectives.

   a) For customers (as organizations implementing the MSaaS RA within their enterprise):

      - The MSaaS RA should define standard capabilities, building blocks, architectural decisions, and other attributes to create a framework of understanding that is sufficient to enable an assessment of conformance of solution architectures.

   b) For suppliers:

      - The MSaaS RA should provide a set of standards and enough specificity that a supplier can use it to drive evaluation of compliance with those underlying standards.

   c) For providers (as integrators):

      - The MSaaS RA should provide a reference for the definition of specific constraints and directions for MSaaS solution implementations.

   d) For standards bodies:

      - The MSaaS RA should provide a reference against which standards can be developed or extended, guidelines provided, more detailed levels of specificity can be defined, etc.

Chapter 3 – ARCHITECTURE CONCEPTS

3.1 OVERVIEW

An architecture of a system or of a federation of systems is, according to IEEE 42010:2011, Ref. [10]:

> "The fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution".

Thus, an architecture provides plans or blueprints for a system.

Architectures can be designed at various levels of abstraction. There is little consensus in general on the various levels of abstraction or on how to name them. The terms used in this document are illustrated in Figure 3-1. Two notions are central: Architecture Building Block (ABB) and Architecture Pattern (AP), Ref. [1]. ABBs are the elements that constitute an architecture, and each ABB should have attributes that specify its function. APs are high-level suggestions for ways of combining ABBs.

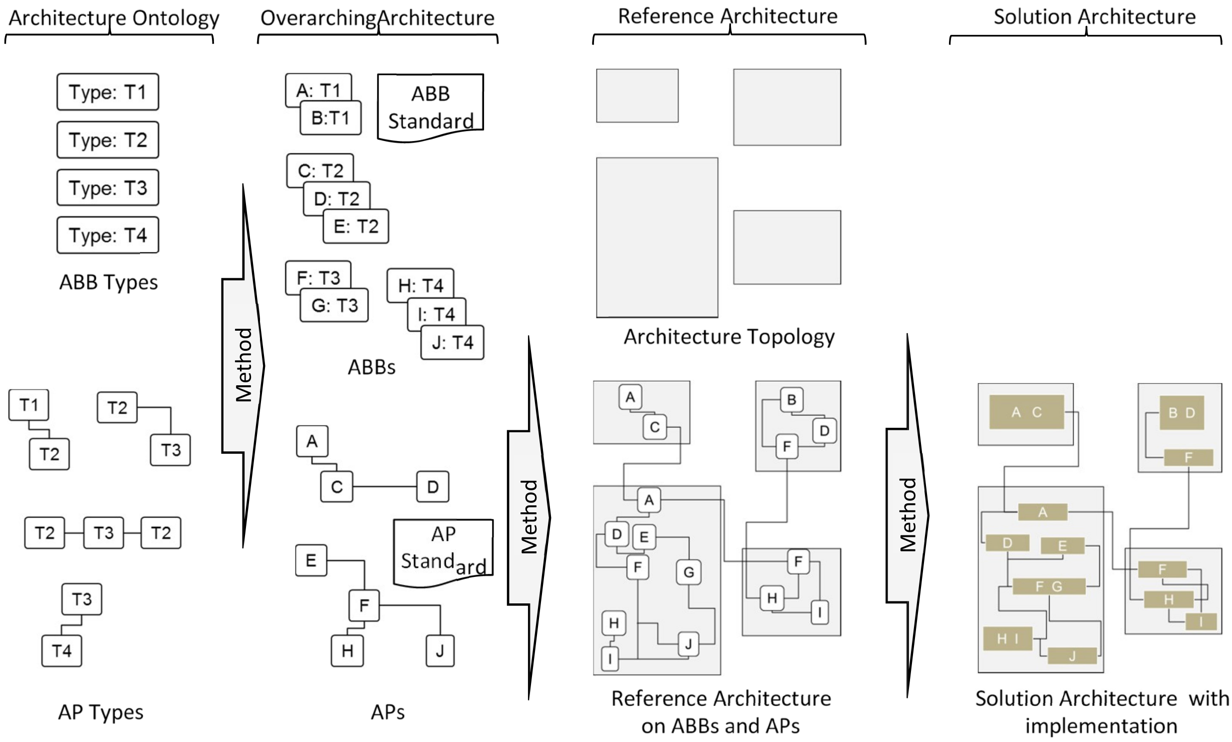

Figure 3-1: MSaaS Architecture Framework.

Figure 3-1 shows several levels of abstraction for architectures. Following Ref. [11], at the highest level, an *architecture ontology* might declare types of ABBs and APs. For example, Ref. [1] declares ABB types, such as '(business) process', 'service', 'repository', 'service container'; and AP types, such as 'consumer pattern', 'service invocation pattern', that are pertinent for any SOA.

Next, actual ABBs and APs of the various ABB types and AP types can be used for declaring a domain-specific *overarching architecture*. The manner in which ABBs and APs are specified might be standardized. For example, an ABB representing a service would be of type 'service' and its specification may follow some standard for service specification.

Then, a *reference architecture* is designed by composing ABBs guided by APs from the overarching architecture. In addition, an architecture topology (or several) should be designed at the reference architecture level to delineate intended systems boundaries and the boundaries in which interoperability standards are enforced. From a reference architecture, individual *solution architectures* (also called target architectures; see Ref. [3]) that specify solution implementations may be derived. There should be methods for refining architectures at one abstraction level to the next [12], [13], [14]. The spectrum of architecture abstraction levels and such methods are what we here refer to as an architecture framework, as shown in Figure 3-1.

Although, the notion of 'architecture framework' is not consistently defined, key points include that such frameworks are ontology-based, open and extensible [15], and that they provide "conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders" [10]. Various frameworks also cover different aspects of architecting [16]; for example, the NATO Architecture Framework (NAF) [3] is a view-based description framework for architecture and The Open Group Architecture Framework (TOGAF) [14] emphasizes architecture governance and the transformation of one type of architecture into another.

It should also be noted that notions of 'overarching architecture', 'reference architecture' and 'target architecture' differ. For example, The Open Group SOA Reference Architecture [1] is a generic template with ABBs and APs that are pertinent for any SOA, and is, in our terminology, an architecture ontology providing ABB types and AP types, rather than a reference architecture.

The types of architecture are summarized in Figure 3-1. In this figure, an architecture ontology provides types of Architecture Building Block (ABB) and Architecture Pattern (AP). An overarching architecture consists of specific ABBs and APs of various types, with standards for specifying ABBs and APs. Various architecture topologies specifying system and interoperability boundaries aid in designing reference architectures using ABBs and APs. From this, solution architectures with implementation-specific systems or solution implementations (olive) can be designed.

3.2 MSaaS ARCHITECTURE FRAMEWORK

In the following sections, we describe an MSaaS architecture framework in terms of the concepts in the previous section.

The architecture ontology will be The Open Group SOA Reference Architecture [1].

The overarching architecture is obtained by defining M&S-specific ABBs of the relevant architecture ontology types. The M&S-specific ABBs will be described in the NATO C3 Taxonomy [7], which is a dynamic library of NATO C3 capabilities.

While the C3 Taxonomy is structured from the viewpoint of C3 capabilities, The Open Group SOA Reference Architecture gives the structure of a SOA. Combining the two gives the necessary architectural structure and functional content for defining MSaaS.

Declaring the M&S-specific portions of this combination gives the MSaaS RA together with an architecture topology that delineates the boundaries for the notion of composed simulation services. We now describe this in more detail.

3.2.1 Architecture Ontology: The Open Group SOA Reference Architecture

The Open Group SOA Reference Architecture (TOGSOARA) [1] gives a structure and generic ABB types that are relevant for any SOA. The MSaaS RA inherits the entire structure but is specific only on ABB types which are pertinent to what is M&S-particular. Figure 3-2 shows the architecture ontology: The Open Group SOA Reference Architecture layers with Architecture Building Block (ABB) examples.

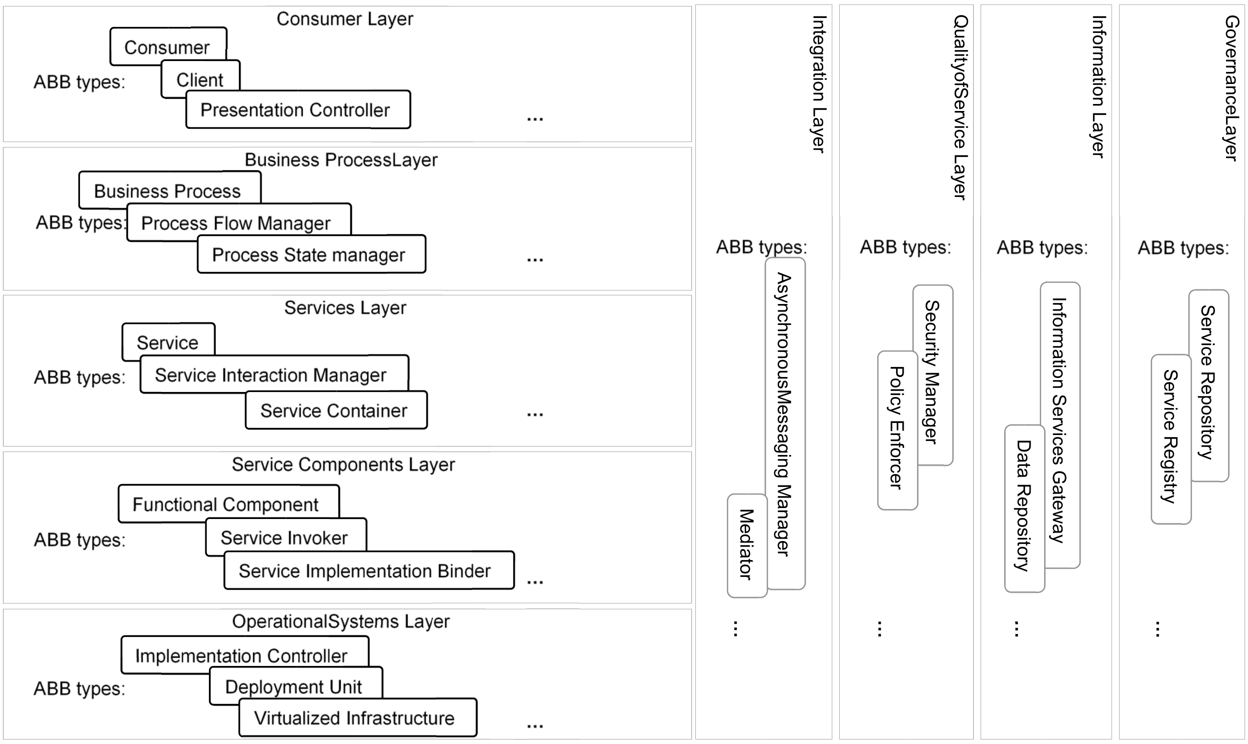

Figure 3-2: Architecture Ontology.

Starting from the bottom, the Operational Systems Layer gives ABB types concerning the operational run-time capabilities in a SOA (i.e., “operational” in a technical sense); such as Implementation Controller, Deployment Unit and Virtualized Infrastructure. The Service Components Layer gives ABB types concerning defining and running services; e.g., Functional Component, Service Invoker and Service Implementation Binder. Both of these layers hold ABB types that are general for any SOA, and at present no M&S-particular ABB types have been identified. Note however, that these layers enable the cloud infrastructure that is vital for MSaaS performance and scalability issues [17]. For the time being, it seems sufficient to use generic infrastructure, but M&S-specific ABBs may be deemed necessary here in the future.

The Services Layer gives ABB types concerning the topical services of the SOA; such as Service, Service Interaction Manager and Service Container. For MSaaS, ABBs that represent Simulation Services and Modelling Services are of type Service. To indicate this one might write, e.g., *MTB Simulation Service:Service* for a particular service ABB that offers a Motor Torpedo Boat (MTB) simulation.

The Business Processes Layer holds ABB types which pertain to the functional processes that arise when combing the SOA’s topical services; for example Business Process, Process Flow Manager and Process State Manager. Business processes are where the business value – the raison d’être of the SOA – manifests itself. For MSaaS, this amounts to combining Simulation Services into Composed Simulation Services, and the business processes are then, in effect, simulations. For the sake of MSaaS, these simulations are themselves packaged as (composed) services. One might create for instance a *Maritime Interdiction Simulation: Business Process* for a maritime interdiction simulation service ABB composed from a number of vessel simulation service ABBs.

The Consumer Layer holds ABB types pertaining to functionality that allows users (human and technical) to access the SOA, such as Consumer, Client, Presentation Controller and Cache. For MSaaS, the front-end, light-weight Simulation Applications and Modelling Applications are represented by ABBs of type Presentation Controller.

There are also four cross-cutting layers: The Integration Layer holds ABB types which concern integrating ABBs from various layers, the Quality of Service Layer concerns availability, reliability, security, and safety in the SOA, the Information Layer concerns the management of information shred in the SOA, the Governance Layer concerns authoritative rules and management of the SOA. The M&S Repository Services and M&S Registry Services are represented by ABBs of types, respectively, Service Registry and Service Repository in the Governance Layer.

TOGSOARA gives AP types in terms of the ABB types. These patterns are also generic for any SOA.

For example, the Service Invocation pattern describes how the Service Interaction Manager invokes a Service in a Service Container while interacting with the Policy Enforcer (Quality of Service Layer), Access Controller (Quality of Service Layer), Policy Manager (Governance Layer) and Status Manager (Quality of Service Layer). This pattern applies to the MSaaS Services, but the MSaaS RA simply inherits this and other generic SOA patterns, without specifying them in particular for M&S.

3.2.2 Overarching Architecture: The C3 Taxonomy

While the ABB types and the AP types are provided by *TOGSOARA* as the architecture ontology, the actual ABBs and APs of the MSaaS RA are linked in from the NATO C3 Taxonomy [7]. The C3 Taxonomy is a library for NATO's Consultation, Command and Control (C3) capabilities; see Figure 3-3 for a high-level view.

The C3 Taxonomy's top-level capabilities in Figure 3-3 are grouped into Missions and Operations, Operational Capabilities, User-Facing Capabilities, and Back-End Capabilities. Each group of capabilities is further decomposed into more refined and detailed levels of capabilities, such as Business Processes (here, in the sense of defence operational processes), User Applications, Community of Interest (COI) Services, Core Services and Communications Services, and so on. Thus, each category (oval box) represents a division into capabilities and is further divided into sub-categories; i.e., sub-capabilities. At the leaves of these capability trees, one finds individual operational processes (under Operational Capabilities), individual user applications (under User-Facing Capabilities) and individual services (under Back-End Capabilities). This capability structure can be viewed and modified through the C3 Taxonomy's Enterprise Management Wiki.

Thus, the C3 Taxonomy's capabilities are C3-specific ABBs at various levels of detail. This enables architecture work at various levels of refinement and detail. Figure 3-4 shows a closer detail of the taxonomy for CIS capabilities; which will be our focus.

M&S is explicitly represented at the User Applications, COI-Specific Services and COI-Enabling Services levels. Here, User Applications are to be understood in the SOA sense as loosely coupled front-end apps that can be put together readily and rapidly for the purpose at hand. However, in the transition to true service orientation, C3 Taxonomy User Applications also include legacy or proprietary monolithic applications, such as legacy C2IS, Battle Management Systems (BMS) and, indeed, many simulation systems. The COI-Specific Services are back-end technical services that are specific to COIs, and the COI-Enabling Services are more generic cross-COI back-end technical services. The following are the M&S-particular capabilities:

- M&S Applications, which are user-facing capabilities containing Simulation Applications and Modelling Applications ABBs for accessing back-end M&S capabilities;

- M&S Services, which are back-end capabilities containing the Simulation Services, Composed Simulation Services and Modelling Services ABBs; and
- M&S-Enabling Services, which are back-end support capabilities pertaining to M&S containing, e.g., Repository Services and Registry Services ABBs.

One might use the "subtype" relation <: to indicate which groups (classes) ABBs belong to: For example, one might write *COI-Specific Services:>M&S Services:>Simulation Services:>MTB Service:Service* for the MTB simulation service exemplified above.

The ABBs are implementation-independent, and can be realized in various implementations in software to be deployed at different places at different times. Such implementations are capability (service and application) providers in the technical sense, where a piece of software may provide one or more capabilities, and a capability may be provided by one or several pieces of software.

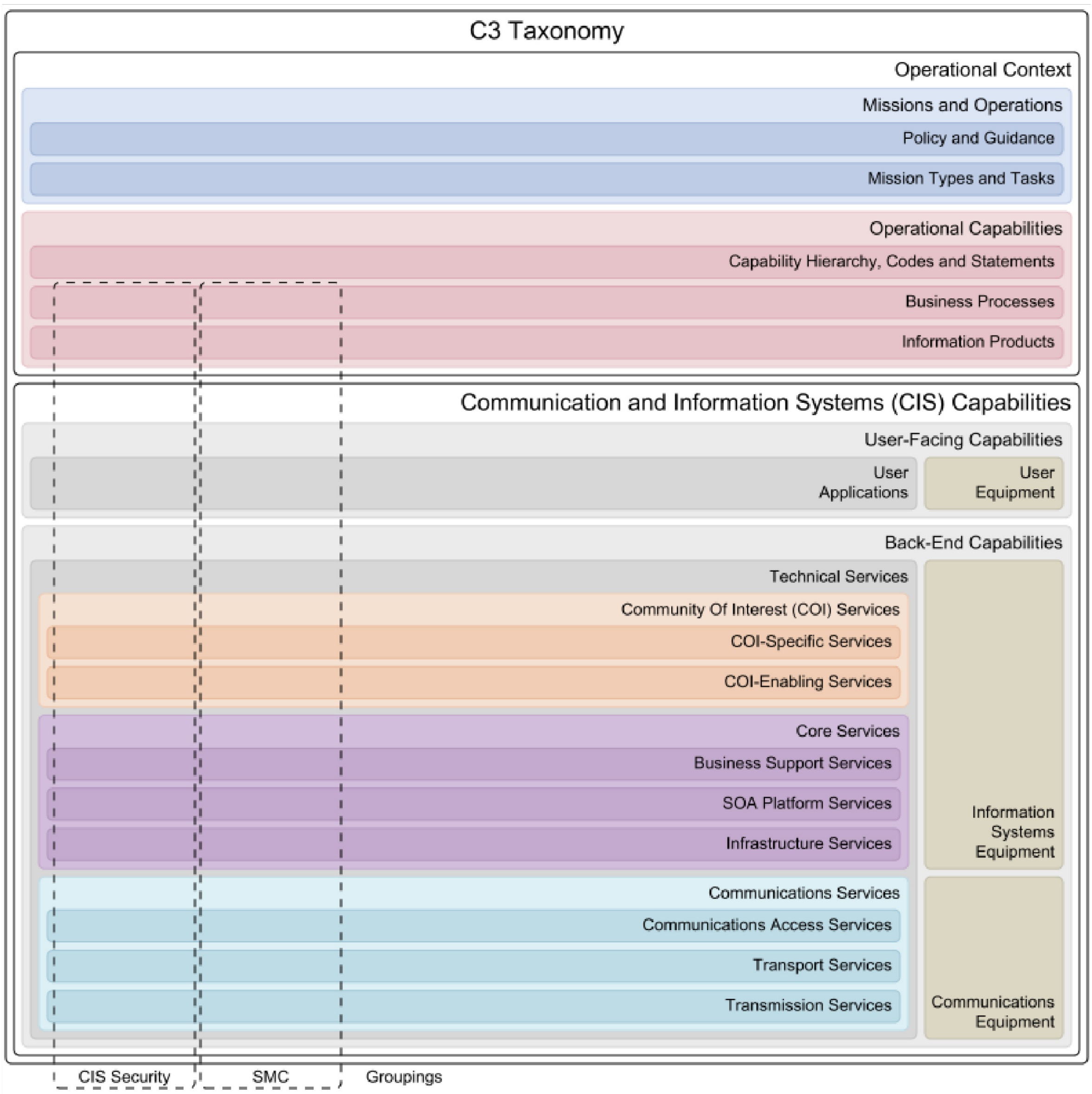

Figure 3-3: C3 Taxonomy – Top-Level View.

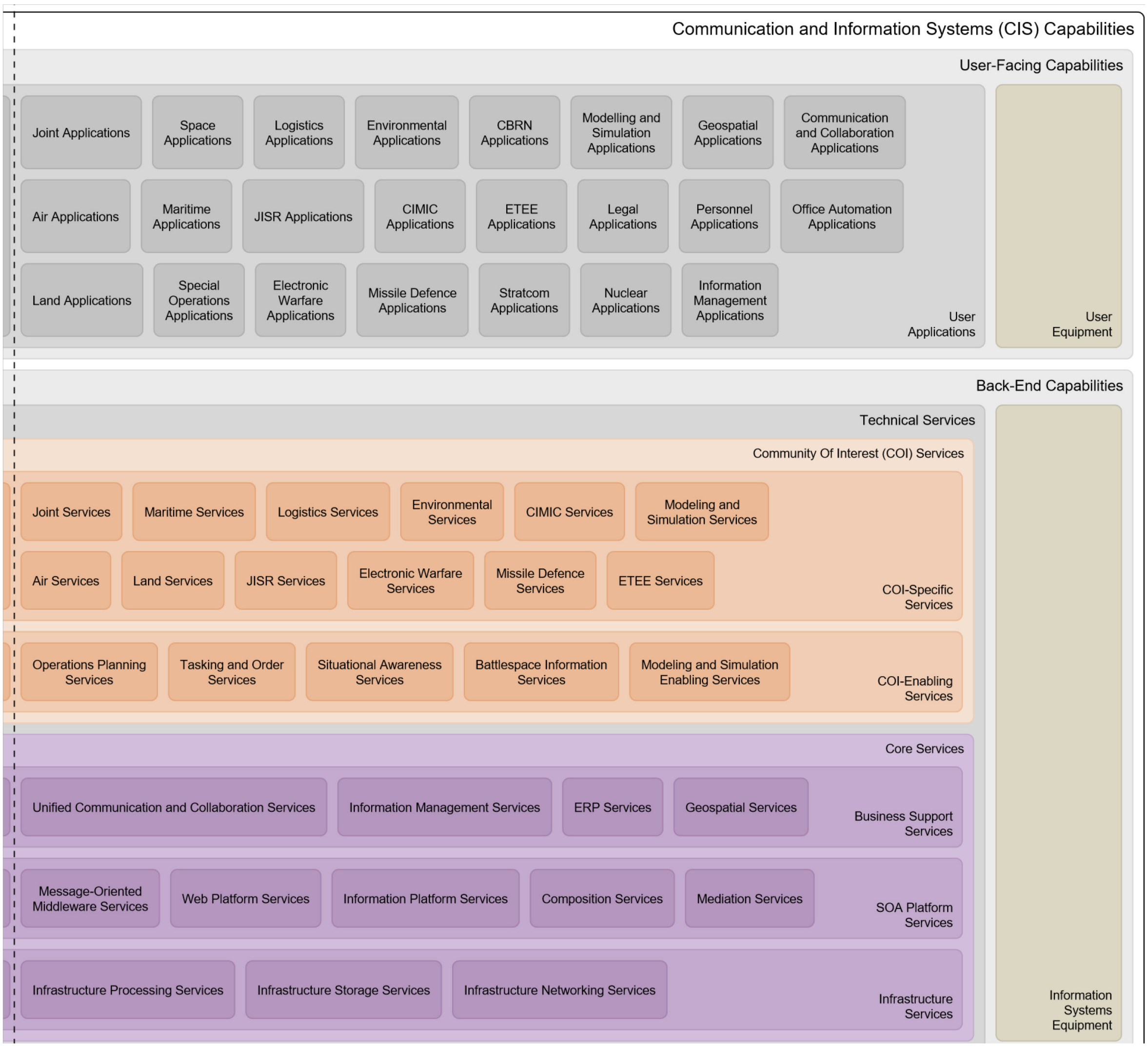

Figure 3-4: C3 Taxonomy (Detail of CIS Capabilities).

An ABB states requirements for development, but it also holds the metadata to be deployed in the Allied Framework for the MSaaS repository. An ABB in the MSaaS RA therefore consists of:

- An implementation-independent description of an M&S capability for the benefit of consumers of that capability, which consists of (see Ref. [4]):
  - An interface (for syntactic interoperability); and
  - A contract (for a degree of semantic interoperability and a specification of contractual non-functional requirements).
- A set of implementation-independent functional and non-functional requirements, for the benefit of developers who will realize the capability in software and hardware.

The C3 Taxonomy is under construction and will likely be in a state of constant flux to meet changing requirements. This is certainly the case for M&S. Work on the MSaaS RA will therefore contribute to the C3 Taxonomy. Figure 3-5 shows the placement of high-level M&S-particular ABBs in the C3 Taxonomy as a result of the MSaaS architecture work. Several of these ABBs are currently not in the C3 Taxonomy. Using the C3 Taxonomy as a library for ABBs and APs means that the most dynamic part of the MSaaS RA is factored out. This also brings the MSaaS RA in context with the other C3 capabilities in NATO's systems portfolio. Figure 3-5 also shows which ABB types the C3 Taxonomy ABBs have, and illustrates the C3 Taxonomy as a library for the MSaaS RA.

The C3 Taxonomy has its own layered structure, which has some resemblance to the layers of *TOGSOARA*, but is nevertheless substantially different. It is important to keep in mind that the MSaaS RA retains the structure and layers of *TOGSOARA*, and simply links dynamically to relevant ABBs in the C3 Taxonomy, which has its own structure.

This document will elaborate on the three main categories above: M&S Applications, M&S Services and M&S-Enabling Services. The elaboration consists of declaring essential main sub-categories, and declaring initial services and applications, but will not include a comprehensive list of services and applications, as this is left for the future continuous elaboration of content in the C3 Taxonomy.

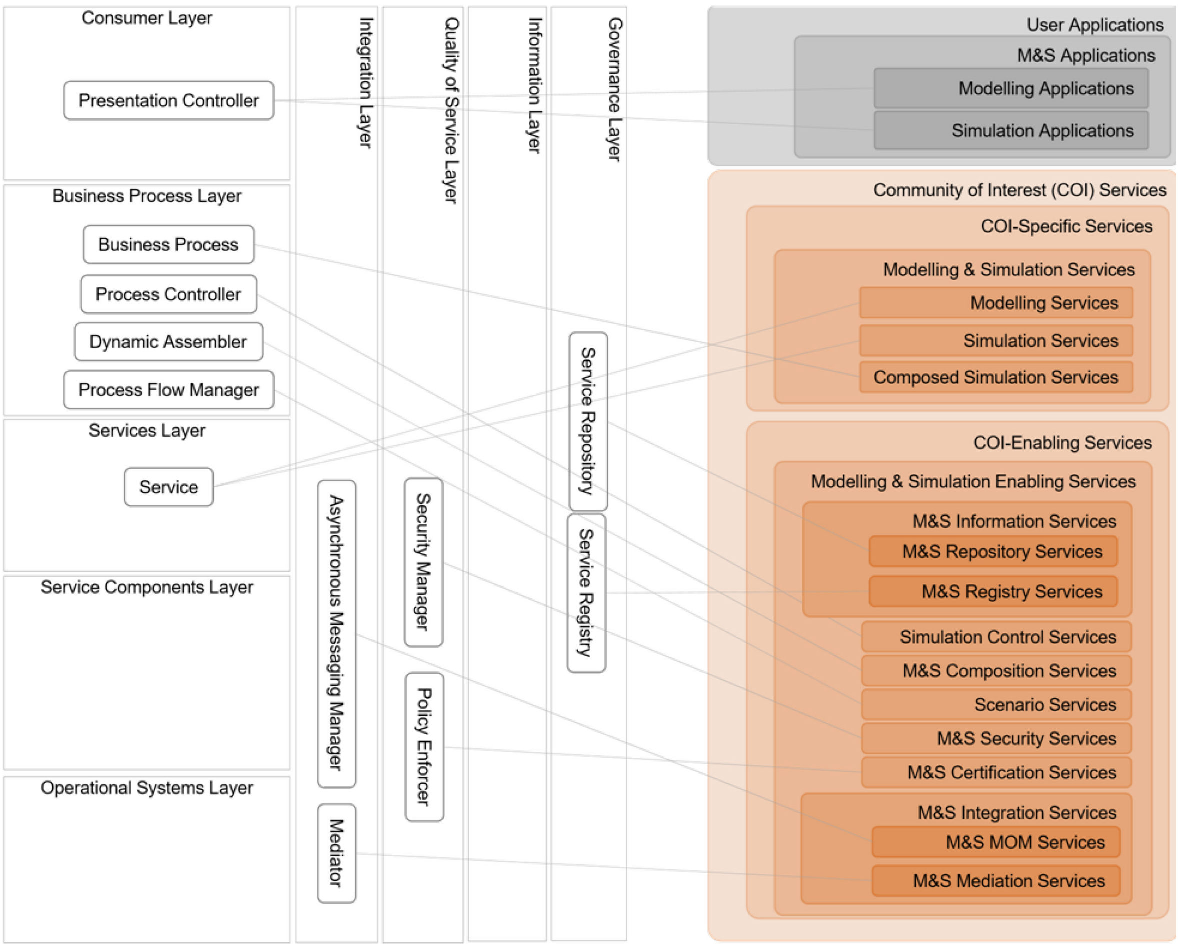

Figure 3-5: The NATO C3 Taxonomy as a Dynamic Library for the MSaaS RA.

3.2.3 Topology: Composed Simulation Services

The central topological issue for MSaaS is the notion of *Composed Simulation Service*; what its components are, what it does – and does not – encompass, and what the relevant boundaries of interoperability are.

At the level of ABBs, a Composed Simulation Service is the result of combining Simulation Services, where the combination of services adheres to a Simulation Environment Agreements and a Simulation Data

Exchange Model, and where various simulation protocols may be used in respective Simulation Protocol Enclaves. Figure 3-6 shows a topology that expresses this. Thus, a Composed Simulation Service is the ABB representation of a multi-architecture simulation environment in terms of the Distributed Simulation Engineering and Execution Process (DSEEP) [18] Multi-Architecture Overlay (DMAO) [19]. M&S Message Oriented Middleware (MOM) Services and M&S Mediation Services are used to integrate the Simulation Services.

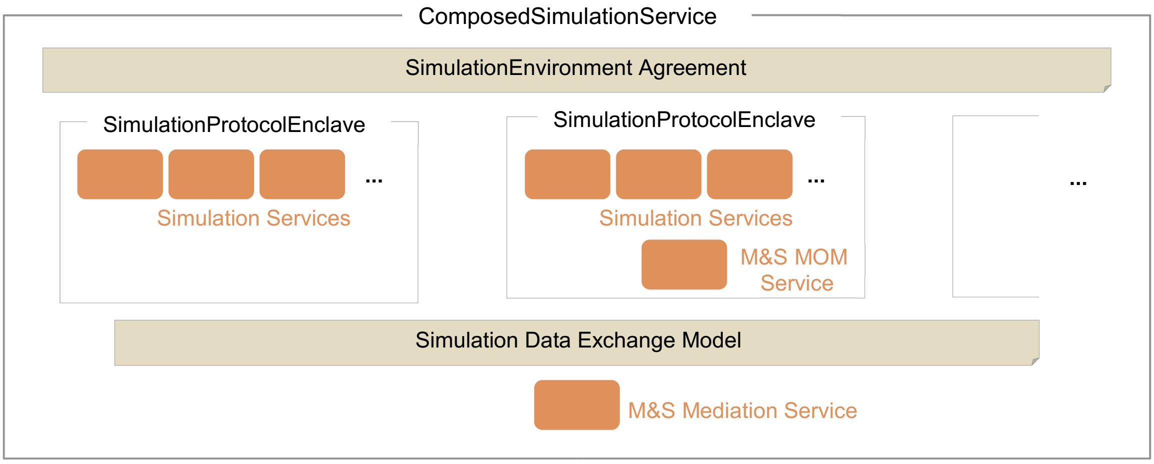

Figure 3-6: Composed Simulation Service.

At the implementation level, MSaaS implies an extension of the DMAO. At present the DMAO identifies enclaves for three simulation architectures: the High-Level Architecture (HLA) [20], Distributed Interactive Simulation (DIS) [21] and Test and Training Enabling Architecture (TENA) [22]. MSaaS adds a fourth enclave for architecture that adheres to industry standard service-oriented technology (*ISSOT*), such as SOAP web services (WS*) [23], Representational State Transfer (RESTful Web Services) [24], Advanced Message Queuing Protocol (AMQP) [25], WebLVC [26], WebSocket [27], etc. This is illustrated in Figure 3-7. Member applications in a given enclave relate to that enclave's implementation of the common simulation data exchange model: a Protocol Data Unit (PDU) set for DIS, a Federation Object Model (FOM) for HLA, a Logical Range Object Model (LROM) for TENA, and a set of service interfaces for ISSOT. Thus, a multi-architecture simulation environment may be a mix of, say, HLA federate applications and web services, as long as they all adhere to the common simulation data exchange model and simulation environment agreement.

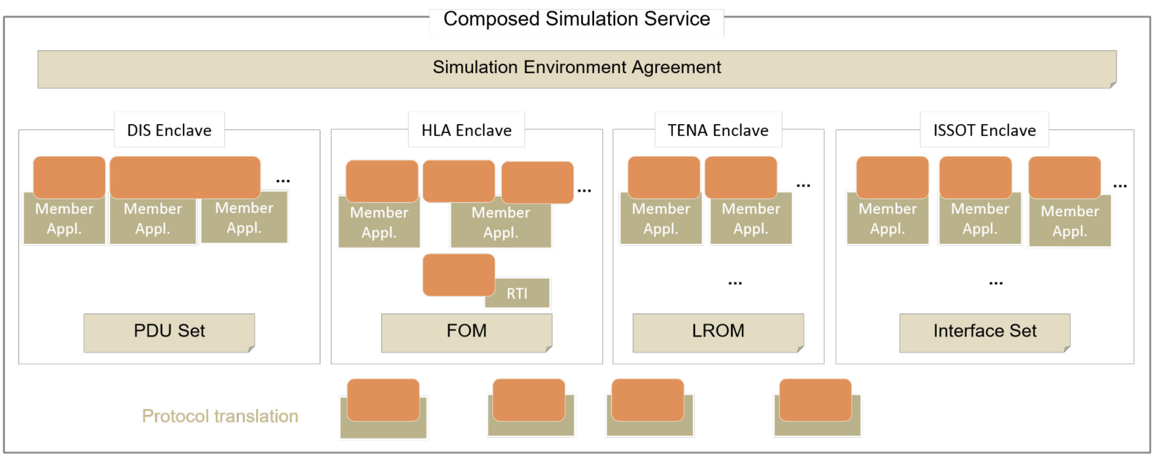

Figure 3-7: Simulation Environment; Concrete Implementations in Olive.

The MSaaS RA implies that simulation environment member applications are to be seen as providers of Simulation Services. The viability of this is affected by several issues, e.g., independence of any particular simulation data exchange model [28] and semantic specification and composability [29], [30]; see Ref. [11] for pointers to a broader discussion. Nevertheless, at the level of implementation-independent ABBs, it is possible to write service descriptions for Simulation Services. Such services may then have various implementations according to particular simulation data exchange model and specific enclave technology. The MSaaS RA embodies the vision that there is added value in designing simulation functionality in terms of Simulation Services, since this is instrumental for the rapid composability and deployment of simulations that the Allied Framework for MSaaS aims to support.

It is essential for packaging Composed Simulation Services that they are clearly delineated in terms of interface and contract. To provide this encapsulation, the MSaaS RA states that the Simulation Environment Agreement encompasses exactly that which adheres to the Simulation Data Exchange Model. Wider agreements must be written when using simulations in conjunction with other systems. For example, in a C2-Simulation System (C2SIM) configuration [31], a semantic agreement (C2SIM federation agreement) might be written for that entire system.

A Composed Simulation Service may interoperate with ABBs from other parts of the C3 Taxonomy. For example, a Composed Simulation Service may serve a C2 system according to standards [32], [33], by way of a designated Simulation Service that exposes the Composed Simulation Service as a service. However, only services that adhere to the Simulation Environment Agreement and the Simulation Data Exchange Model are said to belong to the Composed Simulation Service; see Figure 3-8, where the C2 system is represented by the COI Application.

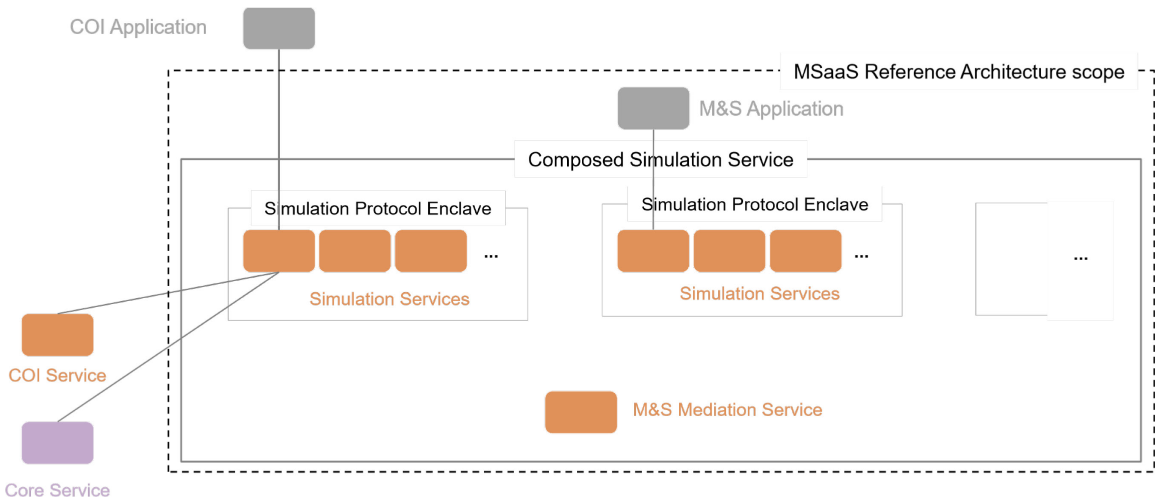

Figure 3-8: Boundary of Composed Simulation Service and Scope of MSaaS RA.

3.2.4 Scope of the MSaaS Reference Architecture

To summarize the scope of the MSaaS RA, only M&S capabilities are in scope. Figure 3-8 in the previous section illustrates this for the Composed Simulation Service, where the composed service itself is scope, as well as an M&S application that front-ends the Composed Simulation Service, but not an Application or a Service from a COI other than the M&S COI.

Further, only layers of *TOGSOARA* that are identified as pertinent for M&S-particular functionality are specified, and the MSaaS RA only links in ABBs from the C3 Taxonomy's CIS Capabilities: the Consumer Layer links in ABBs from M&S Applications, the Business Process Layer links inn ABBs from

M&S Services (and, of course, not from Business Processes in the C3 Taxonomy's Operational Capabilities), the Services Layer links in ABBs from M&S Services and M&S-Enabling Services and cross-cutting layers link in ABBs from M&S-Enabling Services.

Services and applications from other categories of the C3 Taxonomy are also relevant for M&S capabilities.

For example, when composing simulation services into a simulation, a route planning service from the C3 Taxonomy's Land Services might provide routes for entities in the simulation, and Web Map Services from the C3 Taxonomy's Core Services may provide map data. However, this functionality is provided as services by other communities of interest which are outside the scope of the MSaaS RA and the Allied Framework for MSaaS.

Thus, the MSaaS RA does not specify non-M&S-particular capabilities, such as Core Services (violet in Figure 3-3) or Communication Services (light blue), although these services may indeed be consumed by M&S capabilities. Whenever one identifies a need for an M&S-particular specialization of a capability from these other portions of the C3 Taxonomy, such a specialization is to be declared in the M&S capabilities. This has already been the case, and these are identifiable below with a "M&S" prefix; i.e., M&S Repository Services and M&S Registry Services.

Chapter 4 – MSaaS REFERENCE ARCHITECTURE STRUCTURE

This chapter describes the layered structure of the MSaaS RA. When describing a layer, we also give the main categories in the C3 Taxonomy that are linked in to that layer. These categories are then the high-level ABBs in the MSaaS RA. A summary of the NATO C3 Taxonomy categories can be found in Annex B.

4.1 OVERVIEW

Table 4-1 provides an overview of the MSaaS RA layers and high-level ABBs per layer. A layer is a cohesive set of architecture building blocks that support a set of related capabilities. As mentioned in Chapter 1, the scope of the MSaaS RA is the M&S-specific building blocks. In its present form, some layers of the MSaaS RA are unpopulated, with the understanding that the empty layers may become populated in the future. For these layers, we indicate the assumed C3 Taxonomy categories from which one might find it pertinent to declare M&S-particular ABBs. These ABBs are indicated by "see C3 Taxonomy" in parentheses.

Table 4-1: Layers and Architecture Building Blocks.

Layer	ABB
9. Governance Layer	• M&S Repository Services
8. Information Layer	• M&S Registry Services
7. Quality of Service Layer	• M&S Security Services • M&S Certification Services
6. Integration Layer	• M&S Message-Oriented Middleware Services • M&S Mediation Services
5. Consumer Layer	• Modelling Applications • Simulation Applications
4. Business Process Layer	• Composed Simulation Services • M&S Composition Services • Simulation Control Services • Simulation Scenario Services
3. Services Layer	• Modelling Services • Simulation Services
2. Service Components Layer	• SOA Platform Services (see C3 Taxonomy)
1. Operational Systems Layer	• Infrastructure Services (see C3 Taxonomy) • Communication Services (see C3 Taxonomy)

Layers 6 to 9 are cross-cutting layers as shown in Figure 4-1, e.g., Quality of Service Layer ABBs such as M&S Security Services cross layers 1 to 6. Similarly, Information Layer ABBs cross layers 1 to 7. This is why M&S Security Services are not repeated in layers 1 to 6.

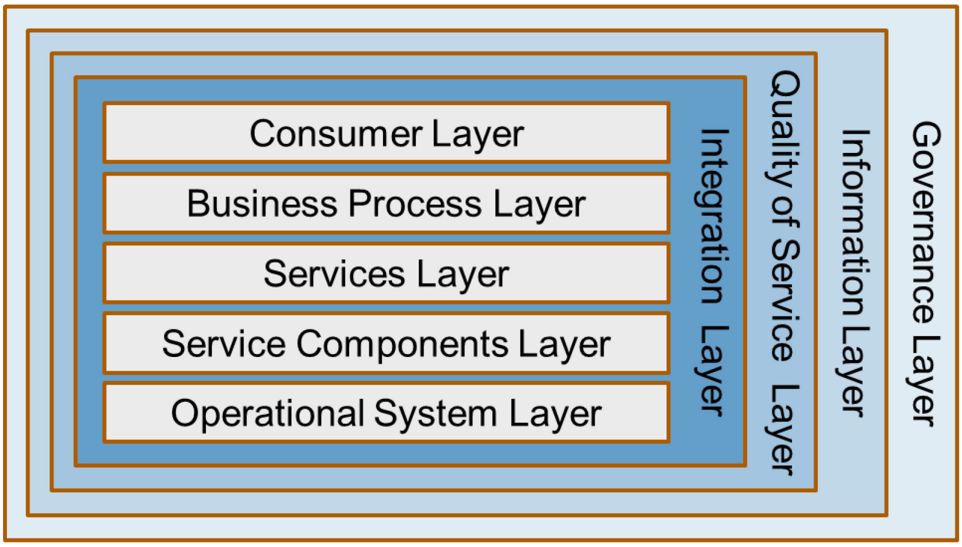

Figure 4-1: MSaaS RA Layers.

4.2 DESCRIPTION OF LAYERS

4.2.1 Layer 1: Operational Systems Layer

The Operational Systems Layer provides the capabilities to interconnect systems, transfer data between systems in accordance with agreed quality parameters, and host infrastructure services in a distributed and/or federated environment.

At present, we have not identified M&S-specific capabilities for this layer. MSaaS will rely on this layer to function, but by using functionality that is generic for any SOA. This layer is therefore empty in the MSaaS RA. If functionality pertaining to this layer needs to be specialized to M&S in the future, it is likely that ABBs from the following C3 Taxonomy categories would be candidates for specialization:

- Core Services: > Infrastructure Services (see C3 Taxonomy).
- Communication Services (see C3 Taxonomy).

MSaaS uses the present generic Infrastructure Services to host M&S Enabling Services and M&S Services in a distributed and/or federated environment. This includes infrastructure security services, infrastructure Service Management and Control (SMC) services, infrastructure processing services, infrastructure storage services, and infrastructure networking services. The infrastructure security services include amongst others digital identity services, authentication services, authorization and access services, and cryptography services. MSaaS is likely to exist in a cloud computing environment, so MSaaS will make use of Infrastructure Services capabilities as provided by cloud computing providers.

The Communication Services provide the capability to interconnect systems. This includes transport services, transmission services, and communications access services.

4.2.2 Layer 2: Service Components Layer

The Service Components Layer provides the capabilities to implement services in a loosely-coupled fashion. At present, we have not identified M&S-specific capabilities in this layer. MSaaS services will rely on this layer to function, but by using functionality that is generic for any SOA. This layer is therefore empty in the

MSaaS RA. If functionality pertaining to this layer needs to be specialized to M&S in the future, it is likely that ABBs from the following C3 Taxonomy category would be candidates for specialization:

- Core Services: > SOA Platform Services (see C3 Taxonomy).

The SOA Platform Services include, amongst others, security services, platform Service Management and Control (SMC) services (such as metering, monitoring, logging, and services discovery), message-oriented middleware services, composition services, mediation services, and information platform services (such as information discovery services and metadata repository services).

4.2.3 Layer 3: Services Layer

The Services Layer provides the capabilities to define and develop services; the core building blocks of a SOA. The two main basic service types for MSaaS are modelling services and simulation services. At present, the C3 Taxonomy contains the M&S Services category (under COI Specific Services), and the MSaaS RA defines two subcategories that reflect these two service types:

- M&S Services: > Modelling Services.
- M&S Services: > Simulation Services.

Modelling Services support simulation engineering processes. Simulation Services are the basic building blocks that deliver simulation functionality and with which simulations are composed.

4.2.4 Layer 4: Business Process Layer

The Business Process Layer provides building blocks for defining processes by aggregating or composing loosely-coupled services. In other words, building blocks for declaring simulations using simulation services. This layer further provides building blocks to control the flow and execution of processes.

This layer in the MSaaS RA includes ABBs that represent the composition of simulation services from the Services Layer, as well as services to manage the execution of (composed) simulation services:

- M&S Services: > Composed Simulation Services.
- M&S Enabling Services: > M&S Composition Services.
- M&S Enabling Services: > Simulation Control Services.
- M&S Enabling Services: > Simulation Scenario Services.

The M&S Composition Services provide the capability to compose a simulation from individual services that together meet the objectives of the simulation.

The Simulation Control Services provide the capability to provide input to a simulation execution, control the simulation execution, and collect output from the simulation execution.

The Simulation Scenario Services provide the capability to manage the simulation of scenarios at the technical level.

4.2.5 Layer 5: Consumer Layer

The Consumer Layer defines ABBs that enable consumers to interact with the SOAs services and business processes. This layer is the point of entry for interactive consumers (humans and systems) to interact with the SOAs services and business processes. Consumers can be other systems, other SOAs, cloud service consumers, human users, etc.

The two main basic user application types for MSaaS are modelling user applications and simulation user applications. At present, the C3 Taxonomy contains the M&S User Applications category (under User Applications), and the MSaaS RA defines two subcategories that reflect these two user application types:

- M&S User Applications: > Modelling Applications.
- M&S User Applications: > Simulation Applications.

Modelling Applications enable users to access the modelling services for engineering simulations.

Simulation Applications enable users to access simulation services and composed simulation services Users may here be live, virtual or constructive players or other systems, e.g., C2 systems.

4.2.6 Layer 6: Integration Layer

The Integration Layer provides the capabilities to integrate instances of ABBs from the other layers into systems. This layer supports multi-architecture simulation environments, for example with routing of messages, protocol support and conversion, different messaging/interaction styles, adapters, service messaging, message processing, and transformation.

The MSaaS RA defines the following integration capabilities:

- M&S Enabling Services: > M&S Integration Services: > M&S Message-Oriented Middleware Services.
- M&S Enabling Services: > M&S Integration Services: > M&S Mediation Services.

The M&S Message-Oriented Middleware Services provide the capability to exchange simulation messages between producing and consuming services. This includes capabilities to exchange information in an efficient and time-coherent way.

The M&S Mediation Services provide the capability to exchange messages between incompatible producers and consumers of information. This includes capabilities to transform and translate information.

4.2.7 Layer 7: Quality of Service Layer

The Quality of Service (QoS) Layer provides ABBs for QoS management of various aspects. In this layer M&S-specific capabilities are included, although there are many non-M&S-specific (generic SOA) capabilities in the C3 Taxonomy that are applicable to QoS as well. For example, all the Service Management and Control (SMC) services that deal with metering, logging, monitoring, service discovery, policy enforcement and so on. Thus, many non-M&S-specific QoS related ABBs can be found in the SMC category of the C3 Taxonomy.

The QoS Layer includes the following ABBs, placed under the M&S Enabling Services:

- M&S Enabling Services: > M&S Security Services.
- M&S Enabling Services: > M&S Certification Services.

The M&S Security Services provide the capabilities to implement and enforce security policies in a Multi-Level Security simulation environment. Capabilities include information labelling, guards, and security policy management.

The M&S Certification Services provide the capabilities to verify compliance of individual or composed simulation services with NATO interoperability standards for modelling and simulation. See AMSP-02, Ref. [34], Conformance Testing.

4.2.8 Layer 8: Information Layer

The Information Layer holds ABBs responsible for the management of authoritative information. See AMSP-02, Ref. [34], Service Description Policies. The MSaaS RA places these under a new category M&S Information Services (under M&S Enabling Services):

- M&S Enabling Services: > M&S Information Services: > M&S Registry Services.

The M&S Registry Services provide the means to store, manage and retrieve references to authoritative information required for the execution of simulation environments.

4.2.9 Layer 9: Governance Layer

The Governance Layer holds ABBs responsible for the management of repositories and metadata. Like with the other layers, only M&S-specific capabilities are shown. The MSaaS RA places the M&S-specific capabilities under a new category M&S Information Services (under M&S Enabling Services).

Non-M&S-specific capabilities are not shown in this layer, such as Metadata Repository Services. The Metadata Repository Services category in the C3 Taxonomy provide the capabilities for storing, querying, and retrieving authoritative metadata, which is a generic SOA capability.

- M&S Enabling Services: > M&S Information Services: > M&S Repository Services.

The M&S Repository Services provides the means to store, retrieve and manage models used for simulation purposes.

Chapter 5 – ARCHITECTURE BUILDING BLOCKS

This chapter provides details on the Architecture Building Blocks (ABBs) defined for the MSaaS RA. Section 5.1 begins by providing an overview of the MSaaS RA ABBs and how they relate to the categories defined in the NATO C3 Taxonomy. Section 5.2 provides detail on the M&S Enabling Services providing capabilities, a description and, where relevant, functional and non-functional requirements, related standards, and examples. Sections 5.3 and 5.4 provide similar detail for M&S Services and M&S User Applications, respectively.

5.1 OVERVIEW

An ABB represents a component of the MSaaS RA. It describes a capability and serves as reference for the creation of a solution architecture and solution implementation. A capability is an ability that an ABB possesses and is expressed in terms of requirements. An ABB is technology aware and provides references to enabling technology. Enabling technology provides the means for the technical realization of an ABB in a so-called “solution”.

An ABB has several attributes:

- Functional and non-functional requirements;
- Applicable standards;
- Relationships with other ABBs;
- Related patterns; and
- References to enabling technology.

The MSaaS RA extends the NATO C3 Taxonomy in several places. It uses the M&S Enabling Services and M&S Services categories (high-level ABBs) to provide the most important ABBs for the MSaaS RA. These ABBs are located under the Taxonomy’s COI Enabling Services and COI Specific Services. The MSaaS RA also extends the existing M&S User Applications under User Applications. The extensions to the C3 Taxonomy are shown in Figure 5-1.

The M&S User Applications are further specialized in Modelling Applications and Simulation Applications, as shown in Figure 5-2. The M&S User Applications are a set of capabilities that provide user-facing functionality – the front-ends – to M&S Enabling Services or M&S Services. This is further described in Section 5.3.

The 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. The M&S Enabling Services are specialized in various more specific ABBs, such as security services, scenario services, certification services, and so on. These services are shown in Figure 5-3 and are described in Section 5.2.

The 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 modelling and simulation of (real-world) objects and events. The M&S Services are further specialized in Simulation Services, Composed Simulation Services, and M&S Modelling Services; see Figure 5-4.

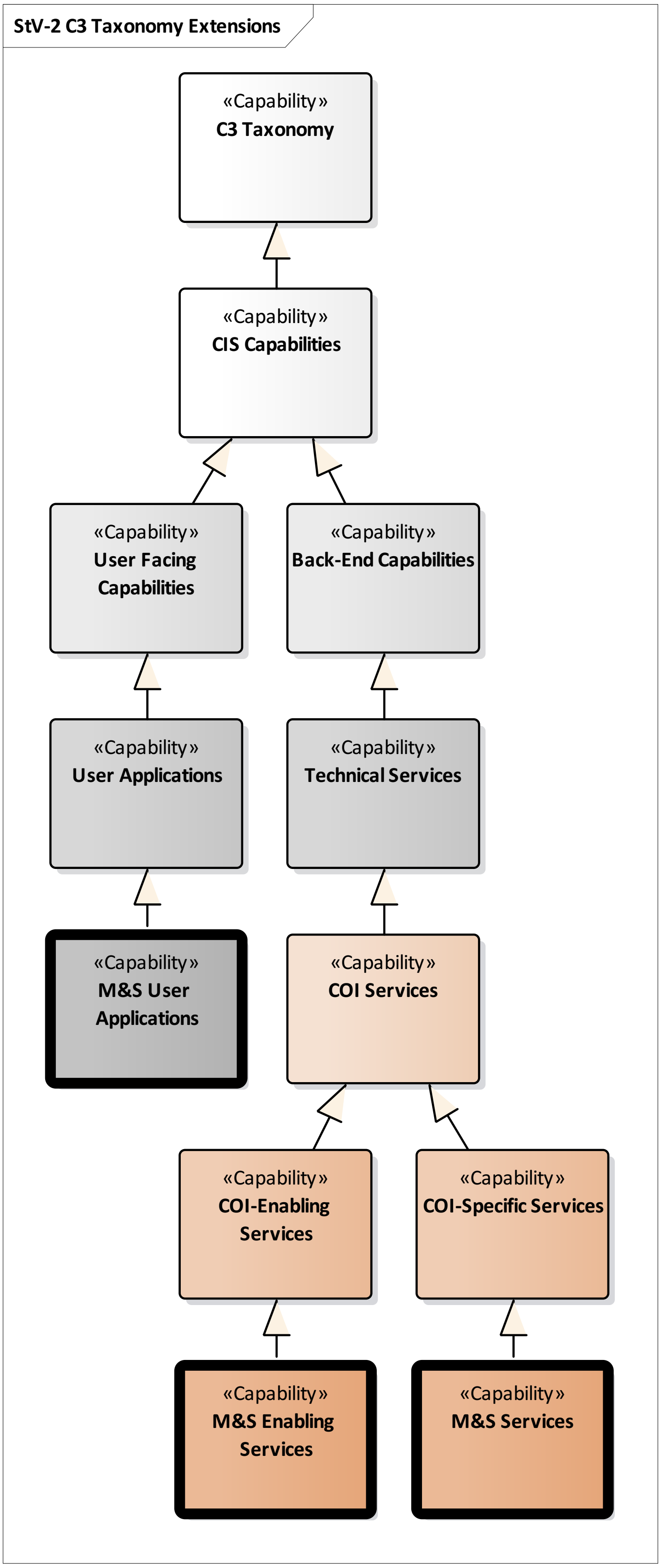

Figure 5-1: MSaaS RA NATO C3 Taxonomy Extensions.

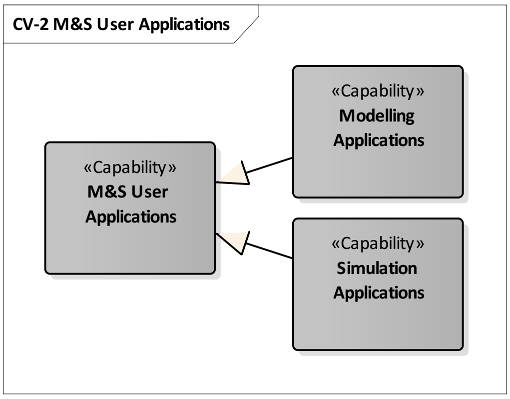

Figure 5-2: M&S User Applications Hierarchy.

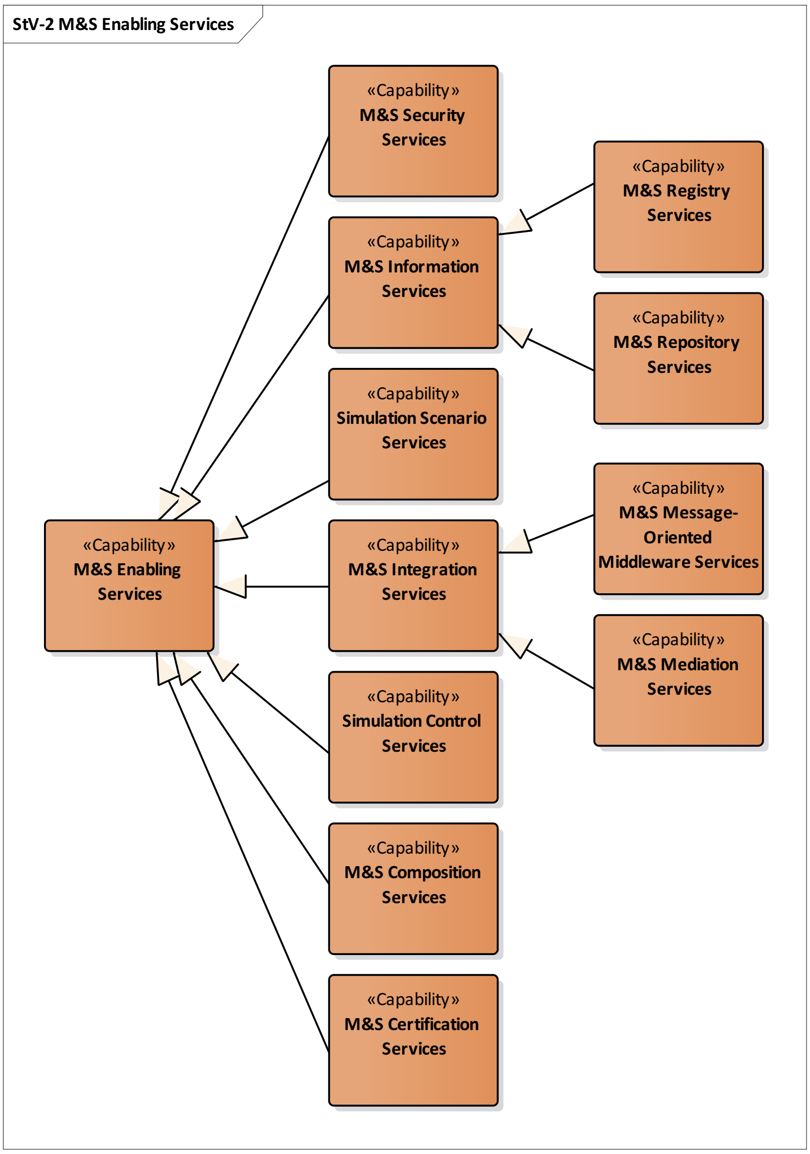

Figure 5-3: M&S Enabling Services Hierarchy.

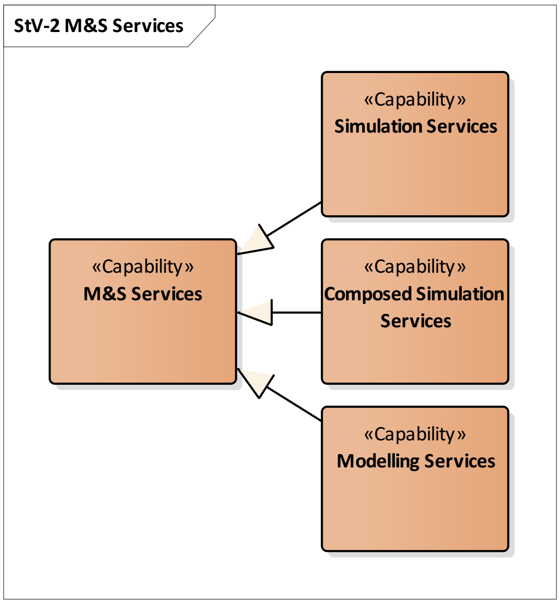

Figure 5-4: M&S Services Hierarchy.

The Simulation Services are central to the MSaaS RA and contain ABBs that model and simulate other COI Enabling Services and COI Specific Services in the C3 Taxonomy, such as Manoeuver Planning Services (e.g., manoeuver planning simulation), JISR Sensor Services (e.g., sensor simulation), or Sonar Prediction Services (e.g., sonar simulation). The number of possible simulation services is very large and ever growing, and they could all be categorized in the taxonomy accordingly. However, this is not in the scope of the MSaaS RA. Thus, for this reason, the Simulation Services are not further specialized.

The Composed Simulation Services are compositions of Simulation Services. These compositions may be orchestrated or choreographed and provide new capabilities by combining Simulation Services. As mentioned in the previous paragraph, the number of possible compositions is large and a further categorization of these is not in the scope of the MSaaS RA.

The Modelling Services 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 engineer an MSaaS solution implementation. These Modelling Services are not further specialized for the same reason as mentioned for the Simulation Services.

The M&S Services are further discussed in Section 5.3.

The ABBs are described in the following sections. Each ABB has a standard set of attributes: requirements, applicable standards, relationships with other ABBs, and examples of enabling technology. When there is no information for a certain attribute the text “None listed” is used. In such a case more information can be found in the sub-ABBs.

5.2 M&S ENABLING SERVICES

Description

The M&S Enabling Services provide capabilities to create a simulation environment in which M&S Services and M&S User Applications are brought together to fulfil the purpose of that simulation environment.

Functional Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- None listed.

Examples

- None listed.

5.2.1 M&S Integration Services

Description

The M&S Integration Services provide the infrastructure to connect producers and consumers of information and support an efficient and time-coherent exchange of simulation data between producers and consumers.

Functional Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- None listed.

Examples

- None listed.

5.2.1.1 M&S Mediation Services

Description

The 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. In doing so, M&S Mediation Services bridge the gap between both parties, enabling interaction that was not possible beforehand.

Functional Requirements

Transform information	• The M&S Mediation Services shall transform data from the producer format and protocol to the consumer format and protocol. • The M&S Mediation Services shall comply with the simulation environment agreements that apply to the producer. • The M&S Mediation Services shall comply with the simulation environment agreements that apply to the consumer.

Non-Functional Requirements

Miscellaneous	• The M&S Mediation Services shall preserve the information that is exchanged between a producer and a consumer in the sense that the information remains consistent and does not become contradictory. • The M&S Mediation Services shall not introduce inconsistencies in the data in the cases where the transformation cannot preserve all the original information.

Applicable Standards

The following two standards are applicable to gateways for simulation environments. At the time of developing this document, these two standards were in the balloting process.

- SISO-STD-014-00-DRAFT, Standard for Gateway Description Language [35].
- SISO-STD-014-01-DRAFT, Standard for Gateway Filtering Language [36].

Relationship with Other ABBs

- Metadata Repository Services: provide services to retrieve metadata, i.e., information about the data to be transformed by the M&S Mediation Services.

Examples

Examples are services that offer simulation gateway functionality (e.g., DIS to HLA), gateway functionality between disparate simulation data exchange models, C2-Simulation gateway functionality, and inter-simulation system coordination management offered as services. Such gateways should include transformation and translation functionality. Central to this is Model-Based Data Engineering, which is a technique to ensure that data exchanged between services is not only syntactically correct, but also semantically correct as interpreted by the interacting systems.

- Simulation gateways (e.g., DIS to HLA) are one example of Mediation Services. C2-Simulation gateways are another example. These gateways include transformation and translation functionality.
- Model-Based Data Engineering is a technique to ensure that data exchanged between services is not only syntactically correct, but also semantically correct as interpreted by the interacting systems [37].

5.2.1.2 M&S Message-Oriented Middleware Services

Description

The M&S Message-Oriented Middleware (MOM) Services provide the capabilities for an efficient and time-coherent exchange of data between producing and consuming Simulation Services, independent of the data format and data content.

The required capabilities of the M&S MOM Services are a design choice at the solution architecture level and depends largely on solution requirements. Therefore, many requirements for this ABB are stated with the term “should”, meaning that it is not required that each implementation of this ABB provides all of the capabilities. The term means that there may exist valid reasons in particular circumstances to ignore a particular requirement, but the full implications must be understood and carefully weighed before choosing a different course and certain enabling technology. For certain solutions particular capabilities may not be required, widening the number of possibilities for enabling technology that can be used in a solution implementation. On the other hand, for certain solutions particular capabilities are required, thus limiting the number of options in enabling technology. Also, organizational policies may dictate (for good reasons) the use of certain standards or enabling technology for M&S MOM Services.

One of the commonly used enabling technologies for M&S MOM Services in M&S domain is the HLA-RTI [20]. However, the number of options for and capabilities provided by M&S MOM Services technology is growing. Different MOM technologies have different functionalities, performance characteristics, and protocols [38]. Architecture patterns can over time support the architect in the identification of required capabilities for M&S MOM Services, and design patterns may help the architect in the selection of suitable enabling technology that fulfils these requirements.

The following quality attributes can be used as aid in the identification of required capabilities for the M&S MOM Services. The list of attributes is not exhaustive and there may be various other attributes that imply certain required capabilities.

<table>
<tr><th>Quality Attribute</th><th>Description</th><th>Function Name</th></tr>
<tr><td>Interoperability</td><td>The ability of different simulations, connected in a distributed simulation, to meaningfully collaborate to simulate a common scenario or virtual world [39].

Turnitsa and Tolk define seven levels of Conceptual Interoperability between simulation models [40]. Levels 1 to 3 can be used to identify required capabilities for M&S MOM Services. Each level includes the capabilities of the lower levels:
Level 1: The M&S MOM Services shall provide a communication protocol for the exchange of data between Simulation Services. On this level, a communication infrastructure is established allowing Simulation Services to exchange bits and bytes, and the underlying networks and protocols are unambiguously defined.
Level 2: The M&S MOM Services shall provide a common protocol to structure the data and shall provide the means to define the format of the information exchange unambiguously. This level defines structure.
Level 3: The M&S MOM Services shall provide the means to use a common information exchange reference model, to share the meaning of the data, and define the content of the information exchange requests unambiguously. This level defines (word) meaning.</td><td>Level 1: Asynchronous Communication

Level 2: Serialization

Level 3: Message Schema</td></tr>
<tr><td>Security</td><td>The capability to protect information and data so that unauthorized persons or systems cannot read or modify it and authorized persons or systems are not denied access to it.

This capability falls also in the Quality of Service Layer, a cross-cutting layer.</td><td>Secure communication</td></tr>
<tr><td>Repeatability</td><td>The capability to repeat successive simulation executions, where the same inputs produce exactly the same outputs.</td><td>Time management</td></tr>
</table>

Quality Attribute	Description	Function Name
Temporal causality	The capability to preserve the relation between a cause and its effect or between regularly correlated events or phenomena. This is capability is particularly important in a distributed simulation where distributed applications perform calculations at different points in time.	Time management

Functional Requirements

Asynchronous communication	• The M&S MOM Services shall provide the means for reliable asynchronous exchange of message between Simulation Services.
Support	• The M&S MOM Services shall support various miscellaneous functions for administration or performance management purposes.
Storage	• The M&S MOM Service should provide the means for persistent storage of messages.
Filtering	• The M&S MOM Services should provide the means for topic based filtering of messages between Simulation Services (i.e., publish/subscribe messaging based on topics). • The M&S MOM Services should provide the means for content based filtering of messages between Simulation Services (i.e., publish/subscribe messaging based on message content).
Time Management	• The M&S MOM Services should provide the means for Simulation Services to exchange messages using a common concept of logical time. • The M&S MOM Services should provide the means for Simulation Services to advance logical time using different time management schemes (e.g., event driven, time stepped).
Serialization	• The M&S MOM Services should provide the means to encode and decode the messages that are exchanged between Simulation Services according to well-defined mechanisms.
Message Schema	• The M&S MOM Services should provide the means to define the schema/structure of the messages that can be exchanged between Simulation Services.
Object Management	• The M&S MOM Services should support lifecycle activities for the messages that are exchanged by Simulation Services (e.g., create, update, delete activities for messages).
Ownership	• The M&S MOM Services should provide the means for Simulation Services to own the data they publish. • The M&S MOM Services should provide the means to transfer the ownership of data to other Simulation Services (e.g., for run-time load balancing of work or multi-level resolution simulation).
Secure Communications	• The M&S MOM Services should provide the means to securely communicate messages between Simulation Services.

Applicable Standards

- IEEE 1516 series: IEEE Standard for Modelling and Simulation (M&S): High Level Architecture (HLA) [20].
- IEEE 1278 series: IEEE Standard for Distributed Interactive Simulation (DIS) [21].
- TENA: Test and Training Enabling Architecture [22].

Relationship with Other ABBs

- None listed.

Examples

- None listed.

5.2.2 M&S Composition Services

Description

The M&S Composition Services provide the capabilities to compose and execute a simulation from existing simulation services. Two common approaches or design patterns for composition are *choreography* and *orchestration* [2].

With orchestration the interaction between simulation services is coordinated. Generally, with this approach, there is one central controller that oversees and directs the simulation services in the composition. The controller has a full overview of the simulation execution – this includes (but is not limited to) orchestration of start-up and shutdown-order of simulation services, orchestration of time advancement, orchestration of information flow, and orchestration of fault handling.

Choreography lacks the central controller that orchestration relies upon and the simulation services interact in a non-directed way. This approach can be seen as a collaborative effort where simulation services work towards a common goal. However, each service will follow a predefined and agreed pattern of behavior. An example of choreography is a simulation where the time advancement is not regulated by a controller, however, there is an agreement that each participant will advance time at a certain pace based on its local clock.

In the same simulation execution, the orchestration and choreography patterns may be mixed. Time advancement may be orchestrated, and patterns of interplay between simulation services may be choreographed through simulation environment agreements. Examples of such agreements are dead-reckoning agreements, entity state update rate agreements, and damage effect agreements in support of fair fight.

Functional Requirements

Manage Lifecycle	• The M&S Composition Services shall provide the means to define a parameterized simulation composition. • The M&S Composition Services shall provide the means to update a defined simulation composition. • The M&S Composition Services shall provide the means to delete a defined simulation composition. • The M&S Composition Services shall provide the means to retrieve a defined simulation composition.

Manage Meta Data	• The M&S Composition Services shall provide the means to associate metadata with a composition. • The M&S Composition Services shall provide the means to define specific metadata to be associated with all compositions. • The M&S Composition Services shall provide the means to define specific metadata to be associated with selected compositions. • The M&S Composition Services shall provide the means to configure the specific metadata to be associated with compositions. • The M&S Composition Services shall provide the means to update metadata associated with a composition. • The M&S Composition Services shall provide the means to remove metadata associated with a composition. • The M&S Composition Services shall provide the means to configure the allowed metadata values. • The M&S Composition Services shall provide the means to associate security classification, policy and releasability with a composition.
Access Compositions	• The M&S Composition Services shall provide the means to retrieve a list of available compositions. • The M&S Composition Services shall provide the means to search available compositions for those matching input criteria. • The M&S Composition Services shall provide the means to search available compositions against metadata values. • The M&S Composition Services shall provide the means to retrieve a single identified composition.
Execute composition	• The M&S Composition Services shall provide the means to start the execution of a simulation composition, and to provide composition parameter values. • The M&S Composition Services shall provide the means to orchestrate the execution of a simulation composition. • The M&S Composition Services shall provide the means to (re)start the execution of a simulation composition. • The M&S Composition Services shall provide the means to pause the execution of a simulation composition. • The M&S Composition Services shall provide the means to stop the execution of a simulation composition.
Programmatic Interfaces	• The M&S Composition Services shall provide APIs to the Manage Lifecycle and Execute Composition functionality.

Applicable Standards

- SISO Federation Engineering Agreements Template (FEAT) [41].
- OASIS Topology and Orchestration Specification for Cloud Applications (TOSCA) [42].
- BOM Assembly [43].

Relationship with Other ABBs

- None listed.

Examples

- The FEAT can be used to capture federation agreements, both choreography and orchestration related agreements.
- The Parallel DEVS Formalism [44] is an example of a distributed modelling and simulation composition system that uses choreography to advance time and exchanges data via messages.
- From the domain of co-simulation several strategies and methods for integrating simulation models via the M&S Message-Oriented Middleware Services can be derived. In general, there are two strategies where a master component typically orchestrates time advancement: loose coupling and strong coupling. With loose coupling simulation models only exchange data at certain points in time and where simulation time always moves forward. With strong coupling simulation, models iterate within each time step until the error estimate falls within a certain tolerance. Here, simulation time within a time step may also go back. For loose coupling two methods are distinguished: Gauß-Seidl and Jacobi. The latter method is quite common in entity level distributed simulation such as DIS (Distributed Interactive Simulation), where member applications all use the same time step and exchange data at agreed points in time. Many references on co-simulation strategies and methods can be found, see amongst others [45], [46], [47], [48].
- The Topology and Orchestration Specification for Cloud Applications (TOSCA) [42] is an open standard that defines an interoperable description of (compositions of) services and applications hosted in the cloud. Comparable, but product specific standards, are the Docker Compose schema and the Kubernetes Pod schema. Open source projects related to the TOSCA standard are the OpenTOSCA ecosystem (http://www.opentosca.org) and Eclipse Winery (https://projects.eclipse.org/projects/soa.winery).

5.2.3 Simulation Control Services

Description

The Simulation Control Services provide the capability to provide input to a simulation execution, control the simulation execution, and collect output from the simulation execution.

Functional Requirements

Execute Simulation	• The Simulation Control Services shall provide the means to initiate a simulation execution. • The Simulation Control Services shall provide the means to terminate a simulation execution. • The Simulation Control Services shall provide the means to adjust the input parameters to a simulation execution at run-time. • The Simulation Control Services shall provide the means to log simulation events. • The Simulation Control Services shall provide the means to control the simulation execution according to a state diagram that defines execution states, triggers and conditions.

Manage Results	• The Simulation Control Services shall provide the means to retrieve the outputs of a simulation execution at any time. • The Simulation Control Services shall provide the means to save the outputs of a simulation execution. • The Simulation Control Services shall provide the means to allow for multiple saved outputs of a simulation execution. • The Simulation Control Services shall provide the means to differentiate between saved outputs.
Initialize Simulation	• The Simulation Control Services shall provide the means to specify the required input parameters to a simulation execution. • The Simulation Control Services shall provide the means to associate information with the input parameters of the simulation execution. • The Simulation Control Services shall provide the means to associate the simulation outputs with an information consumer.
Manage State	• The Simulation Control Services shall provide the means to save the state of a simulation execution. • The Simulation Control Services shall provide the means to attach a bookmark to the saved state of a simulation execution. • The Simulation Control Services shall provide the means to initialize a simulation execution from a saved state. • The Simulation Control Services shall provide the means to delete a saved state of a simulation execution. • The Simulation Control Services shall provide the means to allow for multiple saved states of a simulation execution. • The Simulation Control Services shall provide the means to provide the means to differentiate between saved states of a simulation execution.

Applicable Standards

- OMG State Chart XML (SCXML) [49].
- Distributed Debrief Control Architecture (DDCA) [50].

Relationship with Other ABBs

- M&S Composition Services for the composition of simulation services within a simulation execution.

Examples

- State Chart XML (SCXML) is an XML-based markup language that provides a generic state-machine-based execution environment based on Harel statecharts. The language can be used for orchestration modelling by using a state-machine to specify states, state transitions and triggers with associated actions.

  Several examples of the successful application of SCXML in simulation environments can be found in literature. In Ref. [51] SCXML is used by an Execution Manager to manage the federation state and trigger state transitions via the HLA-RTI Federation Management services. In Refs. [52] and [53] SCXML is used for the orderly management of the startup, execution, and shutdown of distributed simulation components.

- The US Army Research Lab Advanced Training and Simulation Division has developed the Executable Architecture for Systems Engineering as a service for developing, managing, and executing simulation runs. This architecture allows distributed and coordinated execution of simulations along with managing parameters and output data and video [54].

5.2.4 Simulation Scenario Services

Description

The Simulation Scenario Services provide the technical capabilities to define a scenario, to initialize the simulation environment with a scenario, and to handle simulation scenario events.

Functional Requirements

Define Scenario Objectives	• The Simulation Scenario Services shall provide the means to CRUD the objectives of the scenario.
Define Simulation Scenario	• The Simulation Scenario Services shall provide the means to define the location of the scenario. • The Simulation Scenario Services shall provide the means to establish the timeframe of the simulation scenario. • The Simulation Scenario Services shall provide the means to define the weather of the scenario. • The Simulation Scenario Services shall provide the means to define the terrain of the scenario. • The Simulation Scenario Services shall provide the means to define the environment conditions of the scenario. • The Simulation Scenario Services shall provide the means to define the constraints that apply to the simulation scenario. • The Simulation Scenario Services shall provide the means to set up the initial positions of the organizations. • The Simulation Scenario Services shall provide the means to feed the simulation exercise with the actions to be executed. • The Simulation Scenario Services shall provide the means to define the time when the actions are planned to be executed. • The Simulation Scenario Services shall provide the means to define the location where the actions are planned to be executed (way-points). • The Simulation Scenario Services shall provide the means to define the organizations that are responsible to execute each action. • The Simulation Scenario Services shall provide the means to define the desired effects to each action. • The Simulation Scenario Services shall provide the means to define the relevant targets to each action.

Initialize Simulation Environment	• The Simulation Scenario Services shall provide the means to initialize a simulation environment with a scenario for a simulation execution.
Handle Simulation Scenario Events	• The Simulation Scenario Services shall provide the means to detect, emit, listen to scenario-related events in a simulation execution.

Applicable Standards

- SISO-STD-007-2008: Standard for Military Scenario Definition Language (MSDL) [33].
- SISO-STD-011-2014: Standard for Coalition Battle Management Language (C-BML) [32].
- Guideline on Scenario Development for (Distributed) Simulation Environments [55].
- SISO-Guide-GSD-V04-DRAFT: Guideline on Scenario Development for Simulation Environments [56].

Relationship with Other ABBs

- None listed.

Examples

- One proposed approach for Simulation Scenario Services is to use the NATO Architecture Framework to generate a conceptual scenario which can then be translated in to MSDL and CBML [57].
- The SISO Command and Control Systems to Simulation Systems Interoperability (C2SIM) Product Development Group is developing a logical data model that combines the capabilities of existing standards such as MSDL and C-BML to provide services for simulation initialization and task reporting [58].

5.2.5 M&S Information Services

Description

The 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.

Functional Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- None listed.

Examples

- None listed.

5.2.5.1 M&S Repository Services

Description

The M&S Repository Services provides the capabilities to store, retrieve and manage simulation resources and associations with / references to metadata managed by M&S Registry Services. The M&S Repository Services support any simulation resource that may be required for a simulation execution, independent of type and purpose (i.e., service implementations, applications, data files).

Functional Requirements

Manage Simulation Resources	• The M&S Repository Services shall provide the means to associate metadata with simulation resources. • The M&S Repository Services shall provide the means to store an instance of a new simulation resource. • The M&S Repository Services shall provide the means to update existing simulation resources. • The M&S Repository Services shall provide the means to delete existing simulation resources. • The M&S Repository Services shall support simulation resources instantiated as an executable program. • The M&S Repository Services shall support simulation resources instantiated as a data file. • The M&S Repository Services shall provide the means to export simulation resources.
Programmatic Interfaces	• The M&S Repository Services shall provide APIs for Manage Simulation Resources functionality.

Applicable Standards

- OMG Reusable Asset Specification [59].
- OSLC Asset Management [60].
- Proprietary standards, such as Docker Registry API [61].
- See MSaaS Volume 2 [62].

Relationship with Other ABBs

- M&S Registry Services.

Examples

- None listed.

5.2.5.2 M&S Registry Services

Description

The M&S Registry Services provide the capabilities to store, manage, search and retrieve data about (i.e., metadata) simulation resources stored by the M&S Repository Services, such as description of services interface and contract, information about QoS policies, and security and versioning information.

Functional Requirements

Search and Retrieve	• The M&S Registry Services shall provide the means to retrieve a list of available simulation resources. • The M&S Registry Services shall provide the means to search available simulation resources for those matching input criteria. • The M&S Registry Services shall provide the means to search available resources against metadata values. • The M&S Registry Services shall provide the means to retrieve a single identified simulation resource.
Manage Metadata	• The M&S Registry Services shall provide the means to create metadata to be associated with simulation resources. • The M&S Registry Services shall provide the means to associate metadata with simulation resources. • The M&S Registry Services shall provide the means to retrieve metadata. • The M&S Registry Services shall provide the means to update metadata. • The M&S Registry Services shall provide the means to remove metadata. • The M&S Registry Services shall provide the means to define the allowed metadata values. • The M&S Registry Services shall provide the means to associate security classification, policy and releasability with simulation resources. • The M&S Registry Services shall provide the means to identify the simulation resource type.
Programmatic Interfaces	• The M&S Repository Services shall provide APIs for Search and Retrieve, and Manage Metadata functionality.

Applicable Standards

- See MSaaS Volume 2 [62].

Relationship with Other ABBs

- M&S Repository Services.

Examples

- None listed.

5.2.6 M&S Security Services

Description

The M&S Security Services provide the capabilities to implement and enforce security policies for M&S Services. This includes measures to label, guard, and release information that is exchanged between services, or exchanged between M&S Services and User Applications. M&S Security Services enable cross-domain information exchange. M&S pose particular challenges to security, in that simulations of multiple levels of security must interoperate, possibly together with live systems, with performance issues related to real-time or faster-than-real-time simulation.

Note that lower level security measures (such as authorization, single sign on, Identity and Access Control, and also equipment) are provided by the Operational Systems Layer and Service Components Layer of the MSaaS RA, relying on generic and non-M&S-specific security capabilities imported from the C3 Taxonomy. These lower level security measures are not in the scope of the M&S Security Services discussed here.

Functional Requirements

Information Labelling	• The M&S Security Services shall provide functionality to apply metadata to an information object for the purpose of creating a label.
Guard	• The M&S Security Services shall provide functionality to connect networks of different security policy and usage areas.
Policy Administration	• The M&S Security Services shall provide functionality to compose, modify, manage, and control access control policies in a standard policy exchange format, enabling policy enforcement.

Applicable Standards

- None listed.

Relationship with Other ABBs

- Metadata Repository Services [7] for information about data to be labelled.

Examples

- None listed.

5.2.7 M&S Certification Services

Description

Certification of modelling and simulation applications is increasingly important as M&S is used more and more for e.g., military training and decision support. Certification involves processes with manual activities performed by humans, supported by user applications and technical services to verify compliance. The M&S Certification Services in this section 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. The M&S Certification Services support the certification processes, which are not in the scope of the MSaaS RA.

The following list provides an initial set of requirements for the M&S Certification Services.

Functional Requirements

Manage Conformance Statement	• The M&S Certification Services shall provide the means to CRUD a Conformance Statement. • The M&S Certification Services shall provide the means to select test cases based on the Conformance Statement.
Develop Test Cases	• The M&S Certification Services shall provide functionality to CRUD test cases for different levels of interoperability.

Execute Test Cases	• The M&S Certification Services shall provide functionality to initiate the execution of test cases. • The M&S Certification Services shall provide the means to record the results of the execution of a test case.
Test Results	• The M&S Certification Services shall provide functionality to store test results. • The M&S Certification Services shall provide functionality to retrieve test results. • The M&S Certification Services shall provide functionality to delete test results.
Programmatic Interfaces	• The M&S Certification Services shall provide APIs to the Manage Conformance Statement, Develop Test Cases, Execute Test Cases, and Test Results Functionality.

Applicable Standards

- None listed.

Relationship with Other ABBs

- M&S Repository Services for information about Simulation Services and compositions.

Examples

- The US Army Research Lab's Executable Architecture for Systems Engineering has an Advanced Testing Capability for components of a distributed simulation [54].
- The Integration, Verification and Certification Tool (IVCT) is a tool that supports test and verification of simulation components. Use cases and requirements for the IVCT have been proposed by NATO ET-035 [63]. The tool itself is developed by NATO MSG-134 (Distributed Simulation Architecture & Design, Compliance Testing and Certification).

5.3 M&S SERVICES

Description

The 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.

Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- None listed.

Examples

- None listed.

5.3.1 Simulation Services

Description

Simulation Services are a set of capabilities for synthetic representation of (real-world) objects and events. Simulation Services are the service-oriented building blocks of simulations. Simulation services are provided by simulation environment member applications that adhere to the simulation environment's simulation interoperability standard or protocol and that execute underlying models for simulation. Simulation Services can be consumed by other member applications and by consumers outside the simulation environment. Member applications that provide simulation services to consumers outside the simulation environment effectively expose the simulation as a service.

Although the simulation interoperability standard provides the necessary standardized communication protocols, implementation-independent service descriptions (interfaces for syntactic interoperability and contracts for semantic operability) and service discovery mechanisms need to be put into place for a simulation environment to be considered a SOA. Ref. [62] gives templates for simulation service descriptions and describes simulation service discovery mechanisms.

Requirements

- None listed.

Applicable Standards

Simulation architecture specific interoperability standards and protocols:

- IEEE 1516 series: IEEE Standard for Modelling and Simulation (M&S): High Level Architecture (HLA) [20].
- IEEE 1278 series: IEEE Standard for Distributed Interactive Simulation (DIS) [21].

Simulation architecture neutral standards:

- SISO-STD-003-2006: Base Object Model Template Specification [43].

The Base Object Model (BOM) Template Specification defines the semantics and the syntax needed to represent a BOM. A BOM contains the essential elements for specifying aspects of the conceptual model and documenting an interface of a simulation component that can be used and reused in the design, development, and extension of interoperable simulations.

Relationship with Other ABBs

- Simulation Services are the basic components of simulations. They may be composed from other basic services.

Examples

The following non-extensive list gives examples of Simulation Services. These should give rise to ABBs to be included in the C3 Taxonomy.

- Synthetic Environment Services:
    - Services to select or create a geographical area for a simulation:

        - Includes visual data and sensor data (IR, etc.).
        - Includes 2D maps.
    - Services to create weather/meteorological data sets (real sources data, artificial data).
    - Services to define artificial/unreal terrain (for training and exercise purposes):
        - Includes objects, 3D-models, etc.
        - Initializes systems/services before run-time or late joiners during run-time.
        - Uses open, standardized formats and NATO standardized formats (ATP-45, etc.).
        - Supports dynamic changes (e.g., craters, collapsing buildings).
- Route Planning Services:
    - Services to provides Route from A to B:
        - Uses Synthetic Environment Services.
        - Provides different planning options (fastest route, most hidden route, etc.).
        - May use Communication Effects Service to take radio coverage into account.
- Ballistic Weapons Effects Services:
    - Services to provides weapon effects:
        - Uses Synthetic Environment Service.
        - Uses CGF Service.
        - May change terrain/objects, environment.
- Chemical, Biological, Radiological and Nuclear (CBRN) Weapons Effects Services:
    - Services to provide CBRN(e) weapon effects:
        - Simulates CBRN weapon – A weapon designed and manufactured to cause the release of a chemical or biological agent, or to generate a nuclear burst.
        - Uses Synthetic Environment Service.
        - Uses CGF Service and Ballistic Weapons Effect Service - Service may change terrain/objects, environment.
- CBRN Incidents Effects Services:
    - Services to provide CBRN incident effects:
        - Simulates CBRN incident – An occurrence due to the suspected or confirmed presence of chemical, biological, radiological or nuclear substances, either arising from the intention to use them by an aggressor, or following their intentional or accidental release.
        - Uses Synthetic Environment Service.
        - Uses CGF Service.
        - May change terrain/objects and environment.
- Communication Effects Services:
    - Services to calculate communication effects, e.g., can two specific units communicate with each other:
        - Uses Synthetic Environment Service.
        - Takes into account vehicle type, antenna type, modulation, etc.

- Computer-Generated Forces (CGF) Services:
  - Services that provide computer-generated forces (blue, red and other forces):
    - Also known as Threat Generation Service.
    - User can specify number, type, behaviour, etc. of units.
    - May be extended to non-military units like NGOs, first responders, etc.
    - Uses Synthetic Environment Service.
    - May use Order of Battle Service, 3D-Model Service, etc.
- Remotely Piloted Aircraft Services:
  - Services to provides an RPA/UAS (Unmanned Aerial System) model.
  - Services to provides video feed (STANG 4207).
- Tactical Communication Services:
  - Services to provide tactical communication for operators of virtual units.
    - May use Communication Effects Service.
- Report Generation Services:
  - Services to automatically generate certain reports:
    - Considers other reports.
    - Possibility of configuring the service (inputs, outputs, visualization, etc.).

5.3.2 Modelling Services

Description

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.

Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- Modelling Services use the M&S Repository Services to get the descriptions needed during development. Modelling Services can also register the appropriate service instances using the M&S Registry Services.

Examples

- None listed.

5.3.3 Composed Simulation Services

Description

Composed Simulation Services are the results of composing simulation services. They offer entire simulations as services. Examples are any number of composed simulations that are generic enough to be used across many situations and/or occasions; for example, Maritime interdiction simulations for mission rehearsal, war gaming simulations for use in operations planning, simulations for Live, Virtual, Constructive training, etc.

Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with other ABBs

- Composed Simulation Services are created and managed via the M&S Composition Services.

Examples

- None listed.

5.4 M&S USER APPLICATIONS

Description

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.

5.4.1 Simulation Applications

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.

Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- Simulation User Applications interoperate with simulation services and composed simulation services.

Examples

- None listed.

5.4.2 Modelling Applications

Description

Modelling Applications are ABBs that specify front-end functionality for accessing the Modelling Services through the MSaaS Portal.

Requirements

- None listed.

Applicable Standards

- None listed.

Relationship with Other ABBs

- Simulation Modelling Applications interoperate with Modelling Services.

Examples

- None listed.

Chapter 6 – ARCHITECTURE PATTERNS

6.1 OVERVIEW

Architecture Patterns (APs) are best practices for creating "proven" solution architectures from ABBs. Patterns help the architect in the construction of architecture models and composition of architecture views for a solution architecture. Patterns can be generic or specific to a certain application domain.

The concept of design pattern originates as early as 1977 and several books have been published over the years on this topic. One noteworthy book is "Pattern-Oriented Software Architecture, Volume 1: A System of Patterns" [64] by Frank Buschmann *et al*. In this book, three types of patterns are defined:

- An architecture pattern expresses a fundamental structural organization schema for software systems. It provides a set of predefined subsystems, specifies their responsibilities, and includes rules and guidelines for organizing the relationships between them.
- A design pattern provides a scheme for refining the subsystems or components of a software system, or the relationships between them. It describes a commonly recurring structure of communicating components that solves a general design problem within a particular context.
- An idiom is a low-level pattern specific to a programming language. An idiom describes how to implement particular aspects of components or the relationships between them using the features of the given language.

These definitions mainly focus on software architecture. Patterns for systems architecture should generally cover software, hardware and people. However, the underlying idea is the same. Referring to these three types of patterns, patterns related to a reference architecture are at the architectural level, i.e., architecture patterns. Design patterns are more applicable to the construction of a solution architecture, and idioms to a solution implementation.

A pattern has several attributes:

- A name that can be used to reference and talk about the pattern.
- A description of the problem that the pattern helps to solve.
- A description of how the pattern provides a solution to the problem.
- Illustrations to help describe the pattern.

Other pattern attributes are:

- References;
- Functional and non-functional requirements;
- Applicable standards; and
- Examples and known uses.

This chapter covers some of the APs of the MSaaS RA. The purpose of the APs it to show how ABBs in the MSaaS RA may be combined, how they interact with each other, and what information is generally exchanged. The APs serve as reference for designs and for design patterns for solution architectures. The APs in this section are simple examples and illustrate the idea of pattern. For the illustration of the patterns, the NATO Service-Oriented View (NSOV) models are used.

6.2 M&S ENABLING SERVICES PATTERNS

6.2.1 Composition Pattern

6.2.1.1 Problem Description

Simulation services interact with other simulation services to provide an integrated simulation environment. The Composition Pattern describes the ABBs and their required interactions. Implementation of the Composition Pattern results in a simulation environment that treats services as a whole rather than as a set of individual, disjoint services.

6.2.1.2 Solution Description

The Composition Pattern consists of a user-facing M&S Composer Application and ABBs for service composition and repositories. These ABBs interact prior to simulation execution to compose a simulation environment.

6.2.1.3 Illustrations

Figure 6-1 presents the Composition Pattern. A user composes a simulation environment using a M&S Composer Application. This application, in turn, employs the capabilities of M&S Composition Services and the M&S Repository Services. This pattern provides support for the definition, update, retrieval, and deletion of compositions. The M&S Composer Application is user-facing while the other ABBs operate behind the scene.

6.2.2 C2-Simulation Pattern

6.2.2.1 Problem Description

Simulation is an important tool for training C2 system operators and for providing C2 planning support in operational conditions. Improvement of C2 – Simulation interoperability has been, and still is, a topic of various NATO MSGs (e.g., MSG-145, MSG-138, and MSG-085). C2 systems and processes can greatly benefit from simulation, but the integration of C2 with simulation requires a more cost effective and cost efficient way. Often specialized engineers and tools are needed to realize such an integration.

6.2.2.2 Solution Description

Allow for C2-Simulation mediation services that mediate between "live" C2 systems and simulation services. The C2-Simulation mediation services use standards-based interfaces and associated service agreements.

6.2.2.3 Illustrations

The model in Figure 6-2 provides a simple example of the interaction between ABBs in the C2-Simulation pattern. On the left side of the model is the C2 Information System (C2 Application) that transmits C2 messages. The M&S Mediation Services retrieve the schemas of the C2 messages and simulation messages from the Metadata Repository Services. The M&S Mediation Services transform C2 messages to simulation messages and visa-versa, using schemas for the data mediated. The M&S Message-Oriented Middleware Services take care of message routing and the exchange of simulation messages with the Simulation Services. The figure also shows the boundary of the MSaaS RA. Within the boundary are the ABBs, outside the boundary is the C2 Application. Obviously richer and more specific C2-Simulation patterns can (and should) be constructed, incorporating more interface specifics of each of the services into the pattern(s).

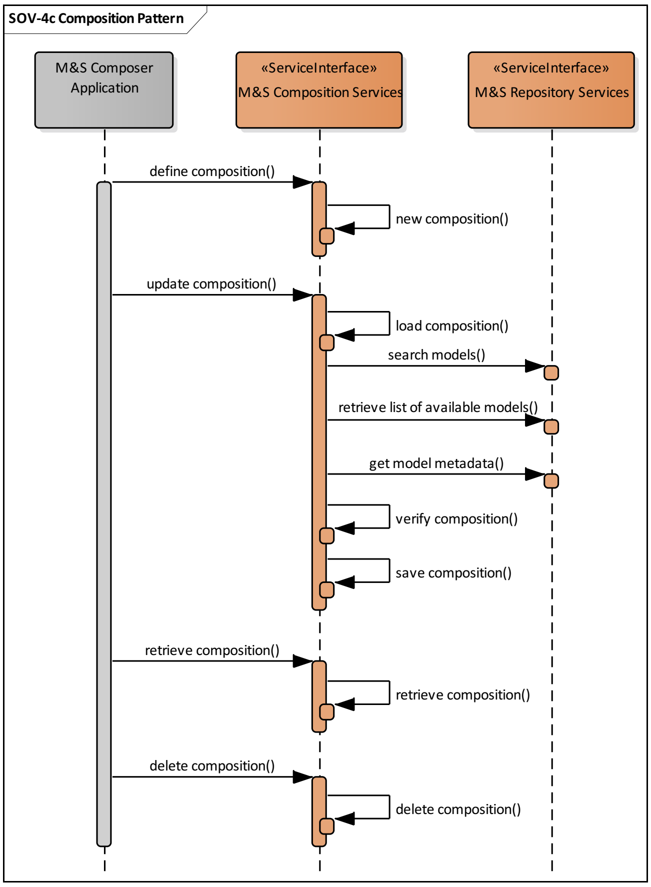

Figure 6-1: Composition Pattern.

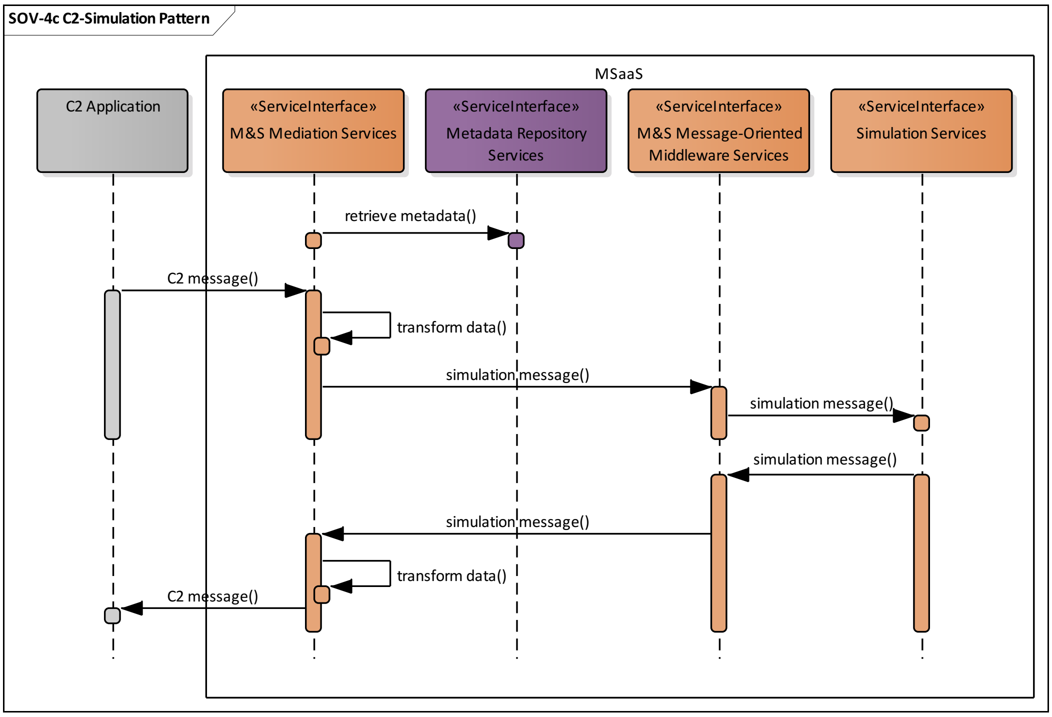

Figure 6-2: C2-Simulation Pattern.

6.2.3 Distributed State Data Pattern

6.2.3.1 Problem Description

For reasons such as performance, fault tolerance, security or reusability, simulation state data needs to be distributed across the member applications in a simulation environment. However, a communication mechanism is needed that supports both an efficient and time coherent exchange of simulation data between member applications. A common view on simulation time and simulation state data must be preserved.

6.2.3.2 Solution Description

A commonly known solution is to use message-oriented middleware services that enable simulation state date to be distributed across member applications. The message-oriented middleware services provide service interfaces to maintain a consistent view on simulation time and simulation state data across the member applications. Solutions for such middleware include the HLA-RTI.

6.2.3.3 Illustrations

Figure 6-3 shows a structural pattern, where member applications use a message-oriented middleware component to exchange simulation state data. Each member application has simulation state data.

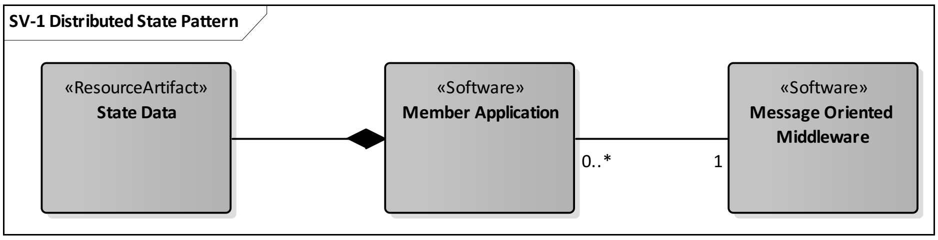

Figure 6-3: Distributed State Data Pattern.

The message-oriented middleware component provides M&S Messages-Oriented Middleware Services, as shown in Figure 6-4.

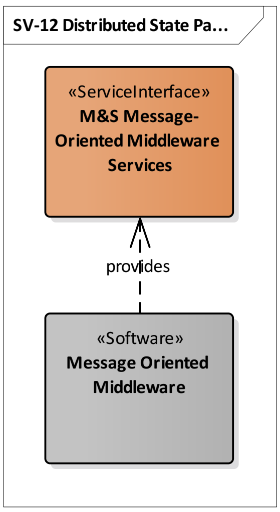

Figure 6-4: Message-Oriented Middleware.

6.2.3.4 Other Information

A related pattern is where the simulation state data is maintained centrally rather than distributed, e.g., via a common database. Note that the M&S Messages Oriented Middleware Services provide the means to distribute simulation state data, rather than centralize data.

6.3 M&S SERVICES PATTERNS

6.3.1 Stateful Pattern

6.3.1.1 Problem Description

Storing and maintaining simulation state in a client and not in a service that the client uses means that the service can be stateless. All required state information for the service is passed in each service request from client to service. This information also includes simulation time. However, for several reasons such as performance or security, simulation state data cannot be maintained in the client and must be maintained in the service. In additional some of the state data must persist over service requests.

6.3.1.2 Solution Description

A typical solution to this problem is a so called stateful service. A stateful service is a service that maintains simulation state data and time over a multiple of service calls, possibly for the lifetime of the simulation execution. State data may be kept in memory for performance.

6.3.1.3 Illustrations

A simple example of stateful service is shown in Figure 6-5. The figure shows a route planning service and several service requests over time. The route planning service can be requested to plan a route (the specific service parameters are not shown in the figure), to start vehicle tracking, to return the current position or to return the remaining route, and to stop vehicle tracking. All quite similar to existing route planning devices in cars. The route planning service can respond promptly to requests like getting the remaining route, since it has all state data available. The client in this example may be a user-facing M&S Application or a member application in the terminology of the DSEEP.

The related service state diagram is shown Figure 6-6. The service state is visible to the client and certain service requests can only be issued in certain states, underlining the fact that the service is stateful.

6.3.1.4 Other Information

A stateful service such as the route planning service in this example may be provided by a member application in the *ISSOT Enclave* (see Section 3.2.3), for instance a HTTP Server. The integration of stateful services from the *ISSOT Enclave* with member applications from the other enclaves (such as an HLA federate) results in what is called a "multi-architecture simulation environment". Several issues need to be addressed to develop such a multi-architecture simulation environment, for example logical time management across the member applications in the different enclaves. Multi-architecture issues and recommended actions are discussed in the DMAO [19].

A stateful service can be quite performant but has the drawback that it is bound to a specific client until the client issues a final service request and ends the session, freeing the service instance for other clients. Several stateful services can be instantiated to increase the number of available sessions for clients, at a cost of additional resources.

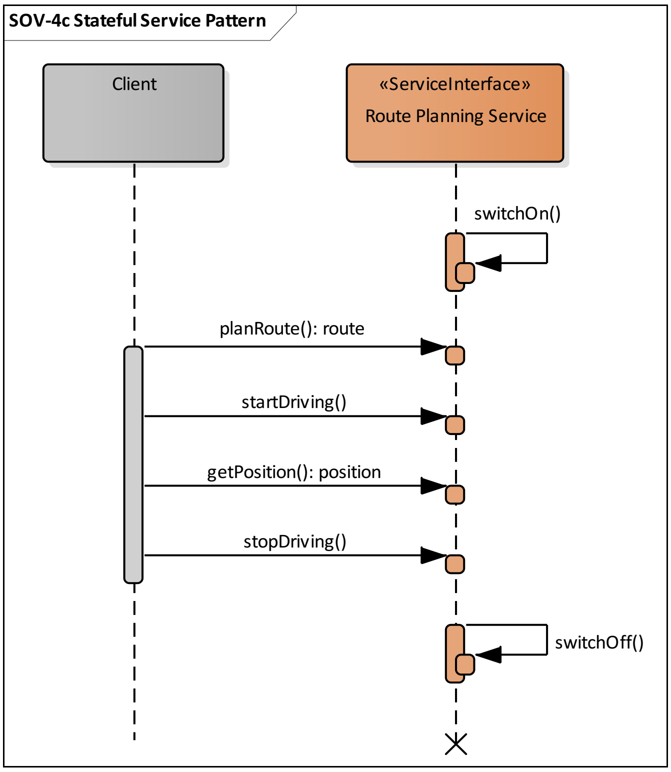

Figure 6-5: Stateful Service Pattern.

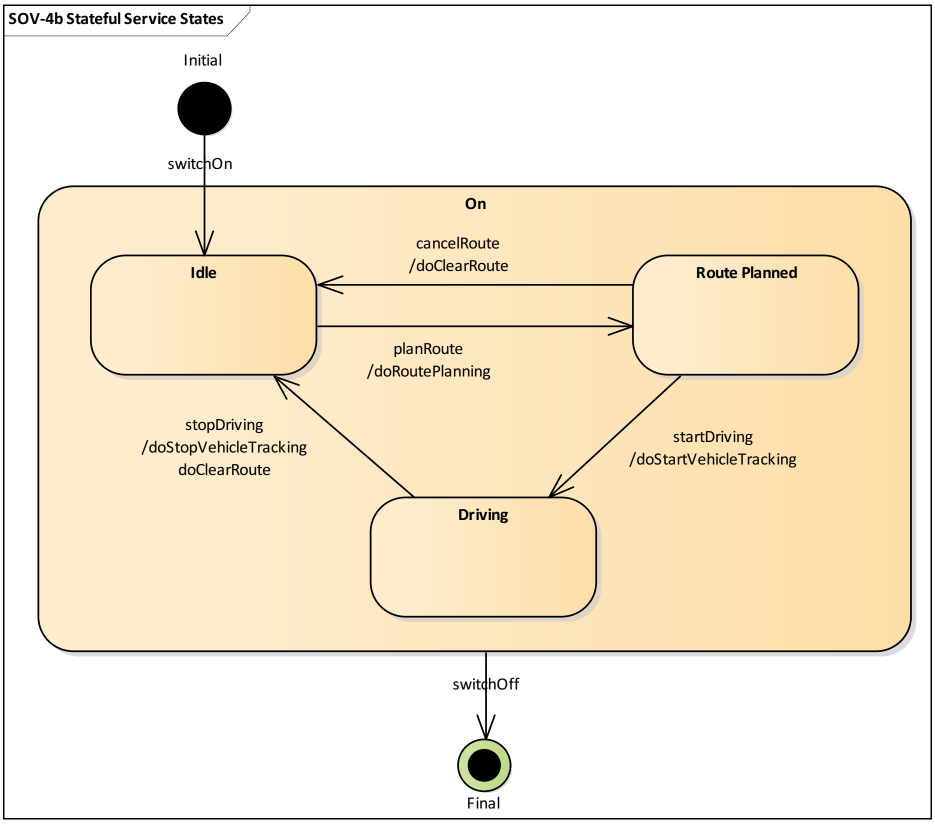

Figure 6-6: Stateful Service State Transition Diagram.

6.3.2 Stateless Pattern

6.3.2.1 Problem Description

Maintaining simulation state data in the service makes the service stateful. However, there may be cases where this is not needed. State data can be maintained in the client also.

6.3.2.2 Solution Description

A stateless service is a service that does not maintain any state between different service calls. Stateless services can be instantiated many times and are not bound to a specific client between different service requests. All required simulation state data (including simulation time) for the service is passed in each service request from client to service.

A stateless service may have various internal states it transitions through while processing a service request, but these states are not visible to the client. A stateless service can use other services to obtain a state (e.g., Database, Message Queue) to complete its client request. Also, a stateless service can use other services to save a particular state.

6.3.2.3 Illustrations

Figure 6-7 provides a simple example of a stateless service, a route planning service that just serves route planning requests from clients. Once the request is handled the service instance is available for other clients.

The route planning service may use static terrain data for planning. As long as this terrain data does not change over time the service can be regarded as stateless.

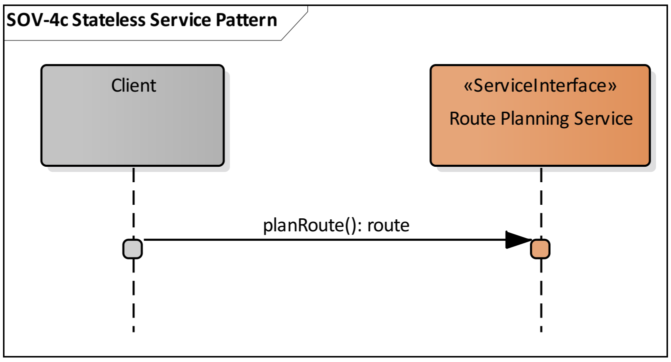

Figure 6-7: Stateless Service Pattern.

6.3.2.4 Other Information

Stateless services from the ISSOT Enclave are relatively easy to integrate with member applications in the other enclaves since the state data resides in the other enclaves. For example, when all the simulation state data resides in the HLA Enclave, the HLA rules are not broken.

6.3.3 Shared Environment Models Pattern

6.3.3.1 Problem Description

Inequivalent environment models are a common and severe obstacle to fair fight when combining simulation components or systems. For example, if a player is able to manoeuvre an armoured vehicle out of line of sight behind a dip in the terrain in one simulation system, but that dip is not included (in sufficient resolution) in the model of another system and can therefore be fired upon, unfair and non-credible situations arise in the federated simulation. Further, terrain alterations, (e.g., due to mortar detonations) and other environmental changes must be reflected equivalently in all systems during a simulation.

6.3.3.2 Solution Description

One solution towards improving credibility and fair fight in environmental factors is to provide environmental elements as services that reside within the simulation environment. For example, a Synthetic Environment Services capability that provides environmental data such as terrain geometry and features to all member applications in the simulation environment.

6.3.3.3 Illustrations

In Figure 6-8, Synthetic Environment Services provided from within the MSaaS simulation environment are consulted for initial environment models and updates to these from simulation services (within the environment), from other COI services outside the simulation environment and from other COI applications (e.g., C2IS and battle management systems). Note that consumers must have operations for reflecting environment updates. In the simulation environment, this can be facilitated, e.g., by a central simulation controller in the manner of HLA. The operations should be standardized.

6.3.4 Shared Computational Effects Models

6.3.4.1 Problem Description

Inequivalent computation models are a common and severe obstacle to fair fight when combining simulation components or systems. For example, if two simulated infantry soldiers engage in combat but relate to inequivalent models for targeting, rules of engagement and weapons effects, unfair and non-credible situations arise in the simulation.

6.3.4.2 Solution Description

One possible solution is to provide computational effects (including behavioural effects) that need to be equivalent as services to be shared across simulations. For example, in MSG-136 demonstrations, a weapons effects server provides common weapons effects services within the simulation environment.

6.3.4.3 Illustrations

In Figure 6-9, computational effects services provided from within the MSaaS simulation environment are consulted for event effects from simulation services. Consumers must have operations for reflecting computational effects. The operations should be standardized. The effects may be relevant for all components in the simulation environment, and may then be facilitated by a central simulation controller (e.g., the RTI in HLA). However, effects but also pertain to only one actor, in which case direct communication between service provider and consumer is relevant.

6.3.5 Shared Presentation of Models

6.3.5.1 Problem Description

Even when simulations relate to shared models, the way the effects are rendered to the user may be inequivalent to the effect of giving non-credible experiences across simulations.

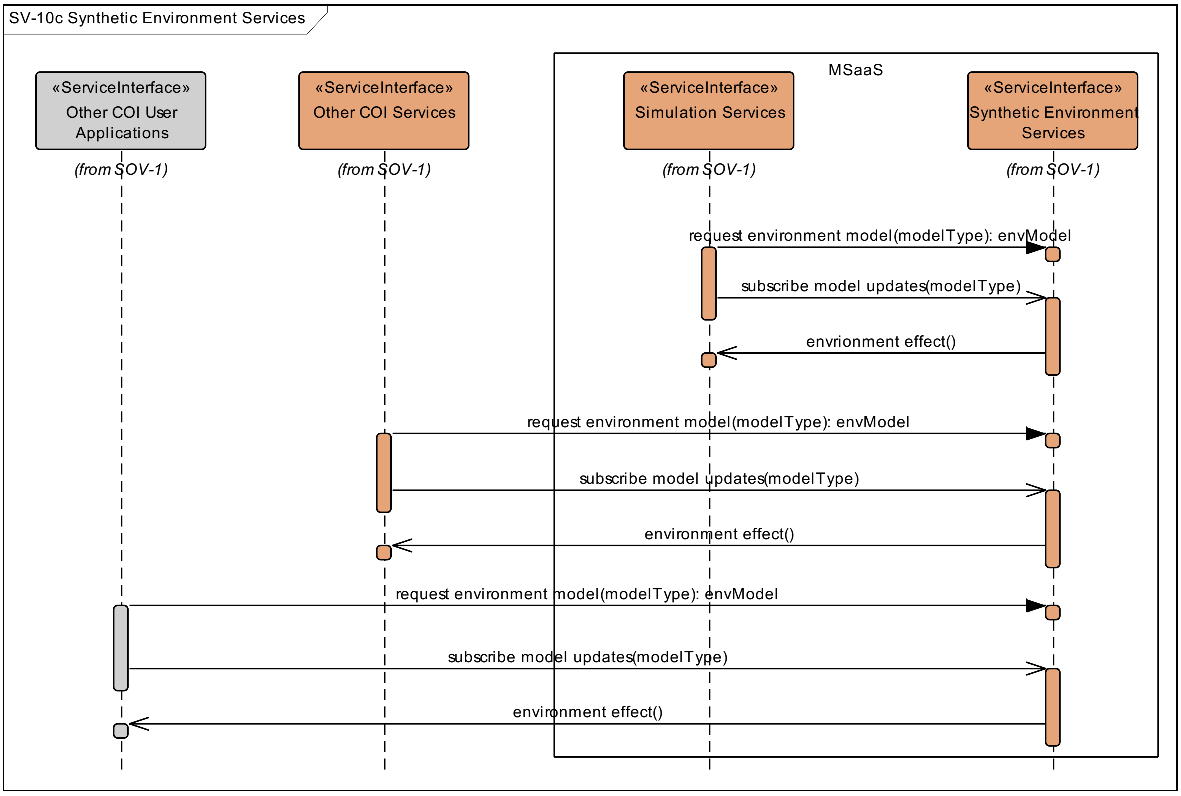

Figure 6-8: Synthetic Environment Services Pattern.

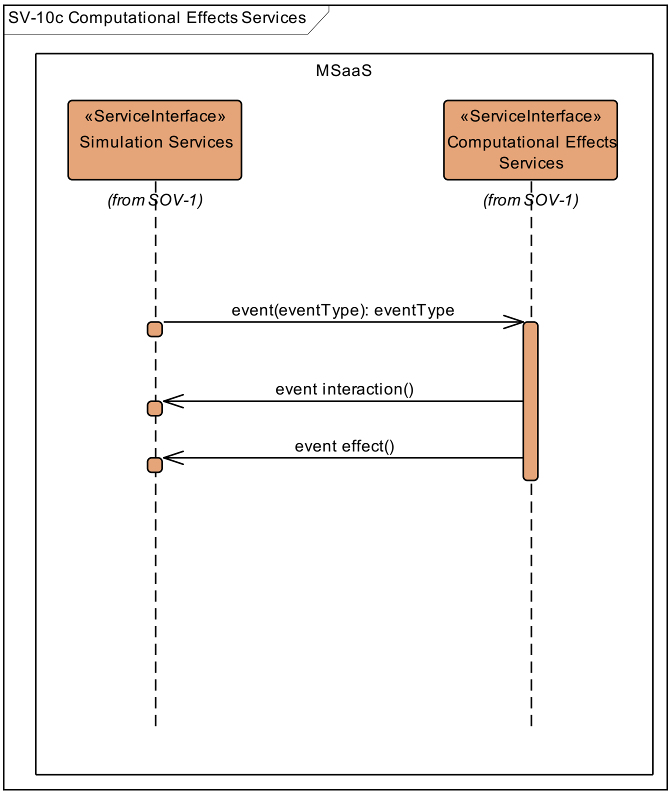

Figure 6-9: Computational Effects Services Pattern.

6.3.5.2 Solution Description

One possible solution is to provide simulation rendering and visualization functionality as standardized services; i.e., user-facing applications. These user-facing applications can then be composed to give user-facing interfaces to simulations that can be embedded in operational systems.

6.3.5.3 Illustrations

In Figure 6-10, M&S user applications subscribe to environment and events to be visualized and rendered by the applications. The applications are to be embedded in operational systems to give operational users standardized interfaces to experience and interact with simulations.

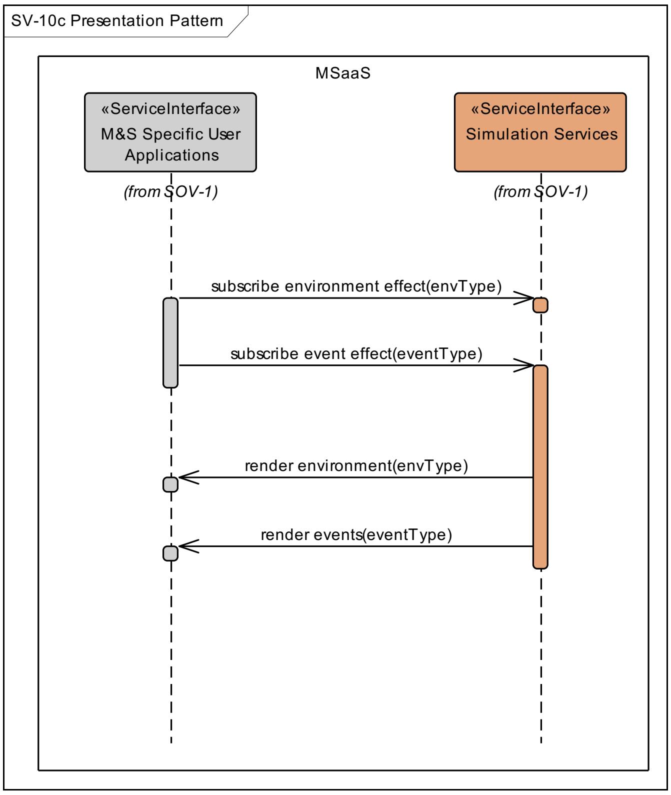

Figure 6-10: Presentation Pattern.

6.3.6 Other COI Service Pattern

6.3.6.1 Problem Description

It is essential for fair fight and credible simulations that also non-simulation functionality is shared. This pertains to real world functionality that may also be used by simulations.

6.3.6.2 Solution Description

Simulation environments may use other COI services (i.e., services that are not dedicated simulation services). For example, a route planning service (which may reside in the C3 Taxonomy's COI-Specific Services -> Land Services -> Terrain Analyzer Services -> Estimate Routing category) may be used by a simulation to compute the route for its simulated entities according to a set of criteria (such as coverage, speed, opportunity to fire, etc.).

6.3.6.3 Illustrations

The pattern in Figure 6-11 shows how simulation services, other COI services and other COI User Applications may interact with a non-simulation COI service. The COI service is oblivious to state in general, and simulation state in particular. Necessary parts of simulation and real world state must be passed to the service. The clients and provider must be synchronized with respect to environment factors that are not included in state.

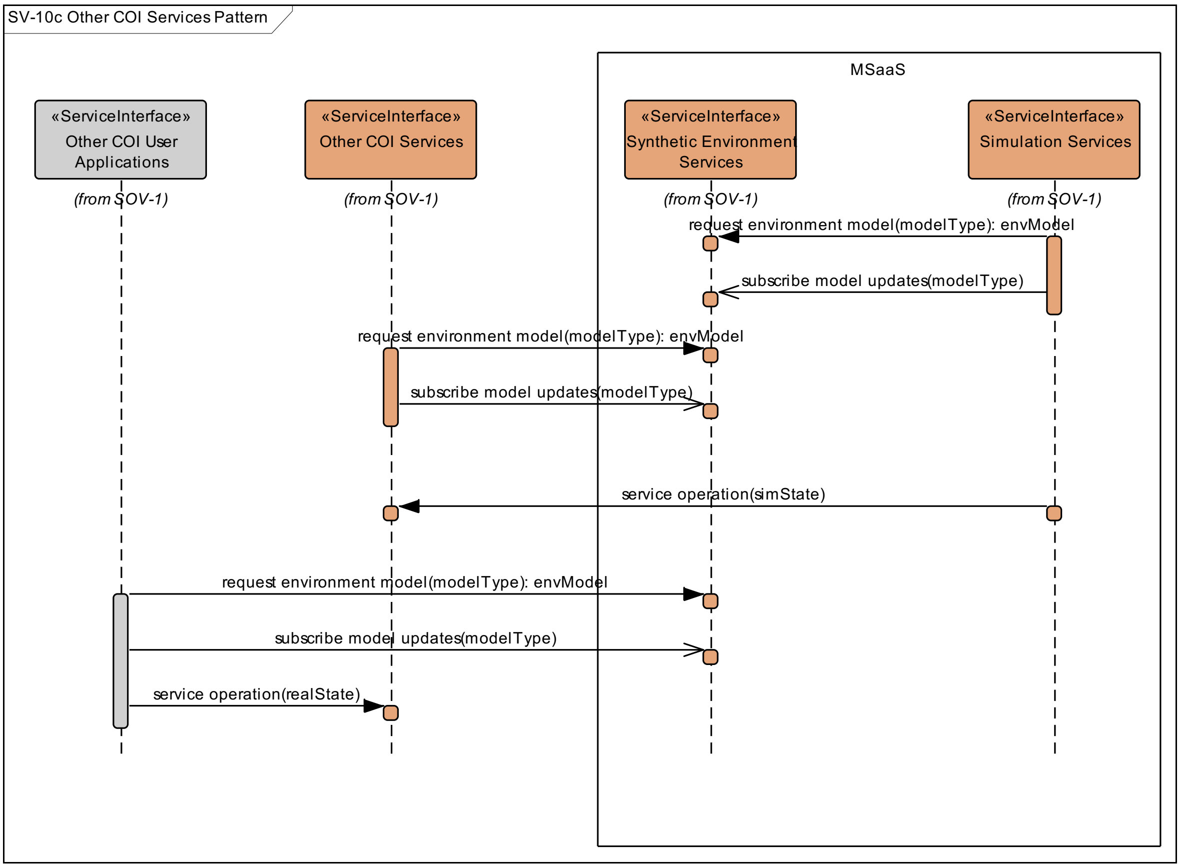

Figure 6-11: Other COI Services Pattern.

Chapter 7 – SUMMARY AND CONCLUSIONS

7.1 SUMMARY

We have outlined the MSaaS Reference Architecture as part of an architecture framework for MSaaS. The purpose of the MSaaS Reference Architecture is to support the technical users of the Allied Framework for MSaaS. The architecture framework for MSaaS provides the means to continuously build and refine the MSaaS Reference Architecture as the demand for M&S capabilities increases and shifts.

The framework in this document lays the ground for the substantial and hard tasks of determining how to divide functionality into loosely coupled M&S capabilities (services and applications), how to write the corresponding M&S capability descriptions (interfaces and contracts), how to define functional and non-functional requirements, and how to develop architecture patterns for a MSaaS simulation environment.

The success of MSaaS relies on solving foundational challenges in M&S; e.g., within conceptual modelling, computation and model reuse, composition and adaptation. Although the MSaaS RA defines architecture building blocks and architecture patterns to address several issues – such as verification and validation of the composition of simulation services, multilevel security issues particular to M&S, performance issues and scalability issues – these issues cannot be resolved without further advancements in research and development in M&S. Since MSaaS offers services to other communities of interest, the success of MSaaS also relies on solving challenges in those domains. The MSaaS RA, with its link to the C3 Taxonomy, can help maintain an updated view on which building blocks and patterns are available. Furthermore, it can also enhance the view on the current state of research and development in the NATOs C3 systems portfolio, and can help to identify where further development of technologies or standards are needed.

The concept of the Allied Framework for MSaaS and its reference architecture are under test in various solutions, where container technology is used to demonstrate the concept and the MSaaS Portal. However, operational use will be the true test and the driver of further research and development.

7.2 RECOMMENDATION

MSG-136 plans to further investigate a number of areas including discovery and composability of M&S services; and to address security aspects of cloud-based solutions in more detail:

The following areas identified in the MSaaS RA need explored and evolved further:

- M&S Composition Services: create and execute a simulation composition. A composition can be created from individual simulation services or from smaller compositions.
- M&S Repository Services: store, retrieve and manage simulation service components and associated metadata that implement and provide simulation services, in particular metadata for automated composition.
- M&S Security Services: implement and enforce security policies for M&S services.
- Update the C3 Taxonomy as mentioned in the MSaaS RA.

The following areas should also be explored:

- To align national efforts and to share national experiences in establishing new MSaaS capabilities.
- Conduct research and development activities on M&S-specific federated cloud environments, federated identity management and cyber secure communications.

- Conduct research on enabling services. Develop *guidelines* and *best practices* for the creation for a simulation environment according to the MSaaS RA.

7.3 CONCLUSION

The main recommendation regarding the MSaaS RA is that NMSG MS3 should be the custodian of the MSaaS Technical Reference Architecture and implementation recommendation. The MSaaS RA should be governed in order to maintain an updated view on which building blocks and patterns are available. Furthermore, it can also enhance the view on the current state of research and development in NATO's C3 systems portfolio, and can help to identify where further development of technologies or standards are needed.

Further research and development activities and efforts are required to mature the MSaaS concept in an operationally relevant environment. Cooperation with the operational user community and participation in exercises is needed to demonstrate the MSaaS vision and capabilities. The above areas should be included in the next phase of the MSaaS concept development and addressed in subsequent updates to the MSaaS RA.

Chapter 8 – REFERENCES

[1] The Open Group, SOA Reference Architecture, C119, Open Group Standard, 2011.

[2] The Open Group, Service-Oriented Architecture Ontology Version 2.0 (C144), 2014.

[3] NATO Architecture Framework v4.0 (draft), 2016.

[4] Bradner, S., Request for Comments: 2119, Network Working Group, Harvard University, 1997. Available at https://tools.ietf.org/html/rfc2119.

[5] NATO STO: Operational Concept Document (OCD) for the Allied Framework for M&S as a Service, STO Technical Report STO-TR-MSG-136-Part-III. To be published.

[6] NATO C3 Board: C3 Taxonomy Version 2.0, 10 November 2015.

[7] NATO: NATO Modelling and Simulation Standards Profile. AMSP-01, Edition (D), Version 1. September 2017.

[8] STANAG 4603 Edition 2, Modelling and Simulation Architecture Standards for Technical Interoperability: HLA, NATO Standardization Office, 17 February 2015.

[9] IEEE: 42010: 2011: Systems and Software Engineering, Architecture Description, ISO, IEC. IEEE, 2011.

[10] Hannay, J., Brathen, K. and Mevassvik, O., A Hybrid Architecture Framework for Simulation in a Service-Oriented Environment, *Systems Engineering 20(3)*, pp. 235-256, 2017.

[11] Hannay, J., Brathen, K. and Mevassvik, O., Agile Requirements Handling in a Service-Oriented Taxonomy of Capabilities, *Requirements Engineering 22(2)*, pp. 289-314, 2017.

[12] Hannay, J., Architectural Work for Modeling and Simulation Combining the NATO Architecture Framework and C3 Taxonomy, *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology 14(2)*, pp. 139-158, 2017.

[13] The Open Group, TOGAF Version 9.1 Enterprise Edition, 2011.

[14] Hilliard, R., The Role of Architecture Frameworks: Lessons Learned from ISO/IEC/IEEE 42010, (unpublished), 2013.

[15] Garnier, J., Bischoff, L., Andre, M., Lavit, B., Peyrichon, M., Blanquart, J. and Scuto, N., Architecture Frameworks – A Standard to Unify Terms, Concepts, Life-Cycles and Principles, *Proc. NATO Information Systems Technology Panel Symposium on Architecture Definition and Evaluation*, no. STO-MP-IST-115, 2013.

[16] Cayirci, E., Modeling and Simulation as a Cloud Service: A Survey, *IEEE Winter Simulation Conference*, pp. 389-400, 2013.

[17] IEEE 1730-2010: Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP), IEEE, 2010.

[18] IEEE Std 1730.1: Recommended Practice for Distributed Simulation Engineering and Execution Process Multi-Architecture Overlay (DMAO), IEEE, 2013.

[19] IEEE 1516-2010: IEEE Standard for Modelling and Simulation (M&S): High Level Architecture (HLA), IEEE, 2010.

[20] IEEE 1278 series: IEEE Standard for Distributed Interactive Simulation (DIS), IEEE, 2012.

[21] Test Resource Management Centre. TENA The Test and Training Enabling Architecture – Architecture Reference Document, The Resource and Management Center, 2002.

[22] Web Services Architecture – W3C Working Group, World Wide Web Consortium, 2004.

[23] Fielding, R. and Taylor, R., Principled Design of the Modern Web Architecture, *ACM Transaction on Internet Technology 2(2)*, pp. 115-150, 2002.

[24] OASIS Advanced Message Queuing Protocol (AMQP), Version 1.0. Edited by R. Godfrey, D. Ingham, and R. Schloming. 29 October 2012. OASIS Standard. http://docs.oasis-open.org/amqp/core/v1.0/os/amqp-core-overview-v1.0-os.html. Latest version: http://docs.oasis-open.org/amqp/core/v1.0/amqp-core-overview-v1.0.html.

[25] Granowetter, L., The WebLVC Protocol: Design and Rationale, *I/ITSEC*, 2013.

[26] Fette, I. and Melnikov, A., The Websocket Protocol, Internet Engineering Task Force (IETF) Request for Comments: 6455, 2011.

[27] Gustavson, P., Chase, T., Root, L. and Crosson, K., Moving Towards a Service-Oriented Architecture (SOA) for Distributed Component Simulation Environments, *Spring SIW*, 2005.

[28] Mojtahed, V., Svee, E. and Zdravkovic, J., Semantic Enhancements when Designing a BOM-based Conceptual Model Repository, *Euro SIW*, 2010.

[29] Mahmood, I., Ayani, R., Vlassov, V. and Moradi, F., Verifying Dynamic Semantic Composability of BOM-Based Composed Models Using Colored Petri Nets, *ACM/IEEE/SCS 26th Workshop on Principles of Advanced and Distributed Simulation (PADS)*, 2012.

[30] SISO: Simulation Interoperability Standards Organization, The Command and Control Systems – Simulation Systems Interoperation (C2SIM) Product Development Group (PDG) and Product Support Group (PSG), June 2015.

[31] SISO-STD-011-2014: Standard for Coalition Battle Management Language (C-BML), SISO, 2014.

[32] SISO-STD-007-2008: Standard for Military Scenario Definition Language (MSDL), SISO, 2015.

[33] NATO: AMSP-02 Allied Framework for Modelling & Simulation (MSaaS) Governance Policies. Edition (A), Version 1. To be published.

[34] SISO-STD-014-00-DRAFT: Gateway Description Language, version 0.7, SISO, 2015.

[35] SISO-STD-014-01-DRAFT: Standard for Gateway Filtering Language, version 0.8, SISO, 2015.

[36] Tolk, A. and Diallo, S., Model based data engineering for web services, IEEE Internet Computing, July 2005.

[37] Eriksson, J., Comparing Message-Oriented Middleware for Financial Assets Trading, KTH, School of Technology and Health (STH), Medical Engineering, Computer and Electronic Engineering, Stockholm, 2016.

[38] Petty, M.D. and Weisel, E.W., 03S-SIW-023: A Composability Lexicon, in SISO, 2003.

[39] Turnitsa, C., Extending the Levels of Conceptual Interoperability, in *Summer Computer Simulation Conference*, IEE CS Press, 2005.

[40] SISO-STD-012-2013: Standard for Federation Engineering Agreements Template (FEAT), SISO, 2013.

[41] TOSCA Simple Profile in YAML Version 1.0, OASIS, 12 June 2016.

[42] SISO-STD-003-2006: Base Object Model (BOM) Template Specification, SISO, 31 March 2006.

[43] Chow, A.C.H. and Zeigler, B.P., Parallel DEVS: A Parallel, Hierarchical, Modular Modeling Formalism, in *Simulation Conference Proceedings, 1994. Winter*, 1994.

[44] Co-Simulation, 2017. [Online]. Available: https://en.wikipedia.org/wiki/Co-simulation.

[45] Hafner, I., Heinzl, B. and Roessler, M., An Investigation on Loose Coupling Co-Simulation with the BCVTB, *SNE Simulation Notes Europe 23(1)*, 2013.

[46] Trčka, M., Co-Simulation for Performance Prediction of Integrated Building and HVAC Systems – An Analysis of Solution Characteristics Using a Two-Body System, *Simulation Modelling Practice and Theory 18(7),* 2010.

[47] Trčka, M., Comparison of Co-Simulation Approaches for Building and HVAC/R System Simulation, Proceedings of the International IBPSA Conference, 2007.

[48] State Chart XML (SCXML): State Machine Notation for Control Abstraction, W3C, 1 September 2015.

[49] SISO: Standard for Distributed Debrief Control Architecture (version 11, draft), SISO DDCA, 2015.

[50] Van den Berg, T.W., Jansen, R.E.J. and Ufer, H., 09S-SIW-009: Design Patterns for and Automation of Federation State Control, SISO, 2009.

[51] Gaughan, C., Gallant, S., Athmer, K., Murphy, S. and Snively, K., 13F-SIW-017: Bringing Next Generation Simulation into the Land of Practicality, SISO, 2013.

[52] Snively, K., Gaughan, C. and Leslie, R., 13F-SIW-019: Runtime Execution Management of Distributed Simulations, SISO, 2013.

[53] Gallant, S., Metevier, S. and Gaughan, C., Systems Engineering an Executable Architecture for M&S, M&S Journal, Spring 2014.

[54] NATO STO: Guideline on Scenario Development for (Distributed) Simulation Environments, NATO Science and Technology Organization, 2015.

[55] SISO-Guide-GSD-V04-DRAFT: Guideline on Scenario Development for (Distributed) Simulation Environments, SISO, 2015.

[56] Khimeche, L., A Disruptive Approach for Scenario Generation: An Agile Reuse Bridging the Gap Between Operational and Executable Scenario (2016-SIW-001), Proceedings of the Simulation Innovation Workshop, September 2016.

[57] Singapogu, S., Gupton, K. and Pullen, M., C2SIM Logical Data Model Development: Scope, Challenges and Future (2016-SIW-009), Proceedings of the 2016 Simulation Innovation Workshop, September 2016.

[58] Reusable Asset (RAS), version 2.2, OMG, November 2005.

[59] OSLC Asset Management 2.0 Specification, OSLC, 25 September 2012.

[60] Docker Registry HTTP API V2, Docker. https://docs.docker.com/registry/spec/api/, 09 Nov 2017.

[61] NATO STO: Modelling and Simulation as a Service, Volume 2: Discovery Service and Metadata. STO Technical Report STO-TR-MSG-136-Part-V. To be published.

[62] NATO STO: Development of a High Level Architecture (HLA) Integration, Verification and Compliance Test Tool (IVCT), NATO ET-035, 2014.

[63] Buschmann, F., Meunier, R., Rohnert, H., Sommerlad, P. and Stal, M., Pattern-Oriented Software Architecture, A System of Patterns, Volume 1, Wiley, 1996.

Annex A – TRACEABILITY WITH NATO C3 TAXONOMY

This annex provides traceability information between the MSaaS RA ABBs and NATO C3 Taxonomy categories.

A.1 NATO C3 TAXONOMY – MSAAS RA ABB

A.1.1 Back-End Capabilities > Technical Services > COI Services

NATO C3 Taxonomy	MSaaS ABB
COI Enabling Services	–
Modeling and Simulation Services	–
Repository Services	M&S Repository Services
Registry Services	M&S Registry Services
Simulation Control Services	Simulation Control Services
Simulation Composition Services	M&S Composition Services
Battlespace Simulation Services	Simulation Scenario Services
Radio Simulation Services	–
Ground Truth Battlespace Objects Services	–
Ground Truth Battlespace Events Services	–
COI Specific Services	–
Modeling and Simulation Services	–
Modeling and Simulation Infrastructure Services	M&S Integration Services
Modeling and Simulation Integration Services	M&S Integration Services

A.1.2 User-Facing Capabilities

NATO C3 Taxonomy	MSaaS ABB
User Applications	–
Modeling and Simulation Applications	M&S User Applications

A.2 MSAAS RA ABB – NATO C3 TAXONOMY

A.2.1 COI Enabling Services

MSaaS ABB	NATO C3 Taxonomy
M&S Enabling Services	–

MSaaS ABB	NATO C3 Taxonomy
M&S Integration Services	Modeling and Simulation Infrastructure Services Modeling and Simulation Integration Services
M&S Mediation Services	–
M&S Message-Oriented Middleware Services	–
M&S Composition Services	Simulation Composition Services
Simulation Control Services	Simulation Control Services
Simulation Scenario Services	Battlespace Simulation Services
M&S Information Services	–
M&S Repository Services	Repository Services
M&S Registry Services	Registry Services
M&S Security Services	–
M&S Certification Services	–

A.2.2 COI Specific Services

MSaaS ABB	NATO C3 Taxonomy
M&S Services	–
Simulation Services	–
Composed Simulation Services	–
Modeling Services	–

A.2.3 M&S User Applications

MSaaS ABB	NATO C3 Taxonomy
M&S User Applications	Modeling and Simulation Applications

Annex B – NATO C3 TAXONOMY

This annex summarizes, in the following tables, the User Applications (Table B-1) and Technical Services (Table B-2) of the NATO C3 Taxonomy The tables use the colour coding scheme as defined for the taxonomy (Figure B-1). Each row in a table represents a capability and provides a relative sequence number, title and brief description of the capability. The User Applications are expanded up to/including to User Applications Entries Level 1, and the Technical Services are expanded up to/including to COI-Specific Services, COI-Enabling Services Entries Level 1.

The tables also include the MSaaS RA extensions to the NATO C3 Taxonomy as described in Chapter 5, replacing the existing M&S-related capabilities in the C3 Taxonomy. These are:

- **M&S Enabling Services** under COI Enabling Services;
- **M&S Services** under COI Specific Services; and
- **M&S User Applications** under User Applications.

A row in a table that is an MSaaS RA extension to the C3 Taxonomy is highlighted with a bold border.

B.1 C3 TAXONOMY

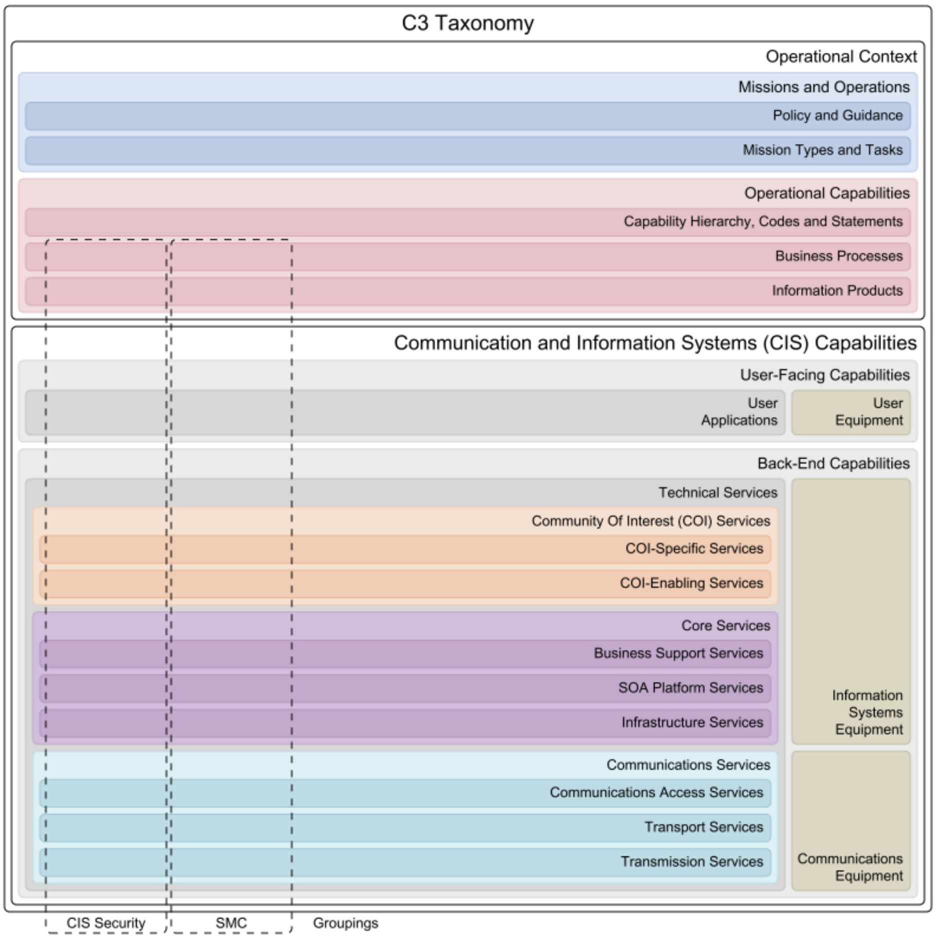

Figure B-1: NATO C3 Taxonomy Overview.

B.2 USER APPLICATIONS

Table B-1: Overview of User Applications.

Nr	Name	Description
1.	User Applications	The User Applications represent the collection of applications – also known as application software, software applications, applications or "apps" – that enable users to perform singular or multiple related tasks through the provision of functionally designed computer software components.
1.1.	CIS Security Applications	The CIS Security Applications enable users to create and maintain a secure environment that meets the security objectives of Communications and Information Systems (CIS) to handle all information.
1.2.	SMC Applications	The Service Management and Control (SMC) Applications enable users to manage, control and monitor services in all layers of the network-enabled enterprise based on centralized and de-centralized business models, and provide the user interfaces to implement, enforce and monitor SMC policies.
1.3.	Joint Applications	The Joint Applications enable users to collect, process, present and distribute information that supports the major functions of joint operations.
1.4.	Air Applications	The Air Applications enable users to collect, process, present and distribute information that supports the major functions of air operations.
1.5.	Land Applications	The Land Applications enable users to collect, process, present and distribute information that supports the major functions of land operations.
1.6.	Maritime Applications	The Maritime Applications enable users to collect, process, present and distribute information that supports the major functions of maritime operations.
1.7.	Space Applications	The Space Applications enable users to collect, process, present and distribute information that supports the major functions of space operations.
1.8.	Special Operations Applications	The Special Operations Applications enable users to collect, process, present and distribute information that supports the major functions of special operations.
1.9.	JISR Applications	The Joint Intelligence, Surveillance and Reconnaissance (JISR or Joint ISR) Applications enable users to collect, process, present and distribute information for intelligence support to operations.
1.10.	Logistics Applications	The Logistics Applications enable users to collect, process, present and distribute information that provides logistics support to operations.
1.11.	Electronic Warfare Applications	The Electronic Warfare (EW) Applications enable users to collect, process, present and distribute information that supports the major functions of Electronic Warfare operations.

Nr	Name	Description
1.12.	Environmental Applications	The Environmental Applications enable users to collect, process, present and distribute information for environmental support to operations.
1.13.	Missile Defence (MD) Applications	The Missile Defence (MD) Applications enable users to collect, process, present and distribute information that supports the major functions of Missile Defence operations.
1.14.	CIMIC Applications	The Civil-Military Co-operation (CIMIC) Applications enable users to collect, process, present and distribute information that supports the major functions of civil-military cooperation support to operations.
1.15.	CBRN Applications	The Chemical, Biological, Radiological and Nuclear (CBRN) Applications enable users to collect, process, present and distribute information that supports the major functions of CBRN Defence operations.
1.16.	ETEE Applications	The Education, Training, Exercises and Evaluation (ETEE) Applications enable users to collect, process, present and distribute information for ETEE support to operations.
1.17.	Stratcom Applications	The Strategic Communications (Stratcom) Applications enable users to collect, process, present and distribute information that supports the coordinated and appropriate use of NATO communications activities and capabilities on behalf of the Alliance policies, operations and activities, and in order to advance NATO's aims.
1.18.	Legal Applications	The Legal Applications enable users to collect, process, present and distribute information that supports the legal community.
1.19.	Nuclear Applications	The Nuclear Applications enable users to collect, process, present and distribute information that supports the major functions of nuclear operations.
1.20.	Human Resources Applications	The Human Resources (HR) Applications enable users to access, process and disseminate information on personnel and manpower.
1.21.	Information Management Applications	The Information Management (IM) Applications enable users to maintain assurance and management of information exchange for Information Superiority across an integrated and federated information sharing network.
1.22.	Geospatial Applications	The Geospatial Applications enable users to view and manipulate geospatial information in two, three or four (with time) dimensional format.
1.23.	Office Automation Applications	The Office Automation Applications enable users to more effectively support, streamline, control and even automate office activities normally undertaken by individual users.
1.24.	Communication and Collaboration Applications	The Communication and Collaboration Applications enable users to more effectively support the sharing of information and corporate knowledge between users across geographic locations.
1.25.	M&S User Applications	M&S User Applications are a set of capabilities that provide user-facing functionality to M&S Enabling Services or M&S Services.

B.3 TECHNICAL SERVICES

Table B-2: Overview of Technical Services.

Nr	Name	Description
2.	Technical Services	The "Technical Services" taxonomy layer represents the collection of services with requirements for software and hardware functionalities that can be reused for different purposes, together with the policies that should control their usage.
2.1.	Community Of Interest (COI) Services	The Community Of Interest (COI) Services support one or many collaborative groups of users with shared goals, interests, missions or business processes.
2.1.1.	COI-Specific Services	The Community of Interest (COI)-Specific Services provide functionality as required by user communities in support of NATO operations, exercises and routine activities.
2.1.1.1	COI-Specific CIS Security Services	The Community of Interest (COI)-Specific CIS Security Services provide the necessary means to implement and enforce CIS Security policies at the COI-specific level.
2.1.1.2	COI-Specific SMC Services	The Community of Interest (COI)-Specific Service Management and Control (SMC) Services provide the means to implement and enforce SMC policies at the COI-specific level.
2.1.1.3	Joint Services	The Joint Services provide unique computing and information services in support of Joint Operations.
2.1.1.4	Air Services	The Air Services provide support to Air Operations.
2.1.1.5	Land Services	The Land Services provide unique computing and information services in support of Land Operations.
2.1.1.6	Maritime Services	The Maritime Services provide unique computing and information services in support of Maritime Operations.
2.1.1.7	JISR Services	The Joint Intelligence, Surveillance and Reconnaissance (JISR) Services provide unique computing and information services for intelligence support to operations.
2.1.1.8	Logistics Services	The Logistics Services provide unique computing and information services for logistics support to operations.
2.1.1.9	Electronic Warfare Services	The Electronic Warfare (EW) Services provide unique computing and information services in support of Electronic Warfare operations, including tools for EW threat assessment, response planning, and coordination of force deployment, and operational reporting.
2.1.1.10	Environmental Services	The Environmental Services provide unique computing and information services for environmental support to operations.
2.1.1.11	CIMIC Services	The Civil-Military Co-operation (CIMIC) Services provide unique computing and information services for CIMIC support to operations.

Nr	Name	Description
2.1.1.12	ETEE Services	The Education, Training, Exercises and Evaluation (ETEE) Services provide unique computing and information services in support of ETEE Management, Education and Individual Training, Collective Training and Exercises and Evaluation.
2.1.1.13	M&S Services	The Modeling and Simulation (M&S) Services provide unique computing and information services for modeling and simulation support to operations.
2.1.2.	COI-Enabling Services	The Community of Interest (COI)-Enabling Services provide COI-dependant functionality required by more than one community of interest.
2.1.2.1	COI-Enabling CIS Security Services	The Community of Interest (COI)-Enabling CIS Security Services provide the necessary means to implement and enforce CIS Security policies at the COI-enabling level.
2.1.2.2	COI-Enabling SMC Services	The Community of Interest (COI)-Enabling Service Management and Control (SMC) Services provide the necessary means to implement and enforce SMC policies at the COI-enabling level.
2.1.2.3	Operations Planning Services	The Operations Planning Services provide the means to facilitate the collaborative development of plans and orders detailing the means to achieve a desired end state by employing available resources.
2.1.2.4	Tasking and Order Services	The Tasking and Order Services provide the means to develop and manage tasks and orders for operational forces.
2.1.2.5	Situational Awareness Services	The Situational Awareness (SA) Services provide the means to support the knowledge of the elements in the battlespace required by a military commander to plan operations and exercise command and control and make well-informed decisions.
2.1.2.6	Battlespace Information Services	The Battlespace Information Services provide the means to allow the discovery, identification, access and collaboration of operationally relevant information.
2.1.2.7	Operational Analysis Services	The Operational Analysis (OA) Enabling Services provide the means to collect, manage, compose and control information resources and analytical services required for conducting operations research and analysis activities.
2.1.2.8	M&S Enabling Services	The 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.
2.2.	Core Services	The Core Services provide generic, Community of Interest (COI)-independent, technical functionality to implement service-based environments using infrastructure, architectural and enabling building blocks.
2.2.1.	Business Support Services	The Business Support Services provide the means to facilitate other service and data providers on the enterprise network by providing and managing underlying capabilities for collaboration and information management.

Nr	Name	Description
2.2.1.1	Business Support CIS Security Services	The Business Support CIS Security Services provide the necessary means to implement uniform, consistent, interoperable and effective web service security.
2.2.1.2	Business Support Service Management and Control (SMC) Services	The Business Support Service Management and Control (SMC) Services provide the necessary means to implement and enforce SMC policies at the enterprise support level.
2.2.1.3	Unified Communication and Collaboration Services	The Unified Communication and Collaboration Services provide the means to a range of interoperable collaboration capabilities, based on open, and commercially available standards that are secure and fulfil NATO and Coalition operational requirements.
2.2.1.4	Information Management Services	The Information Management Services provide the means to direct and support the handling of information throughout its life-cycle ensuring it becomes the right information in the right form and of adequate quality to satisfy the demands of an organization.
2.2.1.5	Enterprise Resource Planning (ERP) Services	The Enterprise Resource Planning (ERP) Services provide the means to cross-functional support for enterprise internal business processes by providing a real-time view of financial resource management, human resource management, supply chain management, customer relationship management, project management and process management activities.
2.2.1.6	Geospatial Services	The Geospatial Services provide the means to deliver network-based access to quality raster, vector and terrain data, available in varying degrees of format and complexity.
2.2.2.	SOA Platform Services	The Platform Services provide a foundation to implement services in a loosely coupled environment, where flexible and agile service orchestration is a requirement.
2.2.2.1	Platform CIS Security Services	The Platform CIS Security Services provide a foundation to implement uniform, consistent, interoperable and effective web service security. They also provide the necessary means to implement and enforce CIS Security policies at the platform level.
2.2.2.2	Platform Service Management and Control (SMC) Services	The Platform Service Management and Control (SMC) Services provide a suite of capabilities needed to ensure that platform services are up and running, accessible and available to users, protected and secure, and that they are operating and performing within agreed upon parameters.
2.2.2.3	Message-Oriented Middleware Services	The Message-Oriented Middleware Services provide functionality to support the exchange of messages (data structures) between data producer and consumer services, independent of the message format (XML, binary, etc.) and content.
2.2.2.4	Web Platform Services	The Web Platform Services provide a suite of functionalities that can be used to support the deployment of services onto a common web-based application platform.

Nr	Name	Description
2.2.2.5	Database Services	The Database Services provide access to shared, structured virtual storage components for data and information persistence as part of the platform environment.
2.2.2.6	Information Platform Services	The Information Platform Services provide capabilities required to manage the enterprise information sphere.
2.2.2.7	Composition Services	The Composition Services will access and fuse data and behavior on demand, and return a single result to the consumer.
2.2.2.8	Mediation Services	The Mediation Services provide a middle layer between incompatible producers of information and consumers of information.
2.2.3.	Infrastructure Services	The Infrastructure Services provide the foundation to host infrastructure services in a distributed and/or federated environment in support of NATO operations and exercises.
2.2.3.1	Infrastructure CIS Security Services	The Infrastructure CIS Security Services provide the necessary means to implement and enforce CIS Security policies at the infrastructure level.
2.2.3.2	Infrastructure Service Management and Control (SMC) Services	The Infrastructure Service Management and Control (SMC) Services provide the means to implement and enforce SMC policies at the Infrastructure level.
2.2.3.3	Infrastructure Processing Services	The Infrastructure Processing Services provide shared access to physical and/or virtual computing resources.
2.2.3.4	Infrastructure Storage Services	The Infrastructure Storage Services provide access to shared physical and/or virtual storage components for data persistence.
2.2.3.5	Infrastructure Networking Services	The Infrastructure Networking Services provide access to high-level protocols and methods that fall into the realm of process-to-process communications across an Internet Protocol (IP) network.
2.3.	Communication Services	The Communications Services interconnect systems and mechanisms for the opaque transfer of selected data between or among access points, in accordance with agreed quality parameters and without change in the form or content of the data as sent and received.
2.3.1.	Communications Access Services	The Communications Access Services provide end-to-end connectivity of communications or computing devices.
2.3.1.1	Communications Access CIS Security Services	The Communications Access CIS Security Services provide a foundation to implement and enforce CIS Security policies at the communications access level.
2.3.1.2	Communications Access Service Management and Control (SMC) Services	The Communications Access Service Management and Control (SMC) Services provide the necessary means to implement and enforce SMC policies at the communications level.

Nr	Name	Description
2.3.1.3	Analogue Access Services	The Analogue Access Services provide the delivery or exchange of analogue signals over an analogue interface port, without manipulation (encoding, compression) of the original signal, and directly interfacing a Transmission Service.
2.3.1.4	Digital (link-based) Access Services	The Digital (link-based) Access Services provide the delivery or exchange of digital signals (synchronous or asynchronous) over a native digital interface port, usually a port providing Transmission Services, at channel access level (e.g. the modem port of a handheld satcom terminal).
2.3.1.5	Message-based Access Services	The Message-based Access Services provide the delivery or exchange of formatted messages, through user appliances that are directly connected to a Transmission Service (e.g. the keypad of a VHF radio).
2.3.1.6	Packet-based Access Services	The Packet-based Access Services provide the delivery or exchange of data (or digitized voice, video) encapsulated in IP packets.
2.3.1.7	Frame-based Access Services	The Frame-based Access Services provide the delivery or exchange of user data, end-to-end, formatted and encapsulated into frames (e.g. Ethernet frames, PPP frames).
2.3.1.8	Circuit-based Access Services	The Circuit-based Access Services provide the delivery or exchange of raw user data, via fractional access to digital lines (circuits), e.g. ISDN BRI, fractional E1, etc.
2.3.1.9	Multimedia Access Services	The Multimedia Access Services provide the delivery or exchange of multimedia data via interaction with the end-user or end-user application.
2.3.2.	Transport Services	The Transport Services correspond to resource-facing services, providing metro and wide-area connectivity to the Communications Access Services that operate at the edges of the network.
2.3.2.1	Transport CIS Security Services	The Transport CIS Security Services provide a foundation to implement and enforce CIS Security policies at the communications transport level.
2.3.2.2	Transport Service Management and Control (SMC) Services	The Transport Service Management and Control (SMC) Services provide the necessary means to implement and enforce SMC policies at the communications transport level.
2.3.2.3	Edge Services	The Edge Services provide the delivery or exchange of traffic flows over different Transmission Services.
2.3.2.4	Transit Services	The Transit Services enable the processes related to connecting IP based Transport Services together, Frame Transport Services together and TDM Transport Services together, either point to point, point to multipoint or multipoint to multipoint over metro and wide area networks.

Nr	Name	Description
2.3.2.5	Aggregation Services	The Aggregation Services provide the aggregation of traffic over parallel converging transmission paths, and involves Packet-, Frame- and Circuit-based Transport Services, where each of the services uses the same Transmission Service to converge into a given network node (often referred to as concentrator).
2.3.2.6	Broadcast Services	The Broadcast Services provide the distribution of transport flows through a combination both the "within the core" and "at the edge" infrastructure types to form a logical "ring".
2.3.3.	Transmission Services	The Transmission Services cover the physical layer (also referred to as media layer or air-interface in wireless/satellite (SATCOM) communications) supporting Transport Services, as well as Communications Access Services.
2.3.3.1	Transmission CIS Security Services	The Transmission CIS Security Services provide a foundation to implement and enforce CIS Security policies at the communications transmission level.
2.3.3.2	Transmission Service Management and Control (SMC) Services	The Transmission Service Management and Control (SMC) Services provide the necessary means to implement and enforce SMC policies at the communications transmission level.
2.3.3.3	Wired Transmission Services	The Wired Transmission Services support physical transfer of data, point-to-point or point-to multipoint, using wired transmission medium amongst two or more static nodes.
2.3.3.4	Wireless Line of Sight (LOS) Static Transmission Services	The Wireless Line of Sight (LOS) Static Transmission Services support the wireless transfer of data amongst two or more static nodes within Line of Sight (LOS) of each other, employing modulated Radio Frequency (RF) carriers in different frequency bands.
2.3.3.5	Wireless Line of Sight (LOS) Mobile Transmission Services	The Wireless Line of Sight (LOS) Mobile Transmission Services support the wireless data of amongst two or more nodes, where one or more of the nodes are operating on the move, within Line of Sight (LOS) of each other, employing modulated Radio Frequency (RF) carriers in different frequency bands.
2.3.3.6	Wireless Beyond Line of Sight (BLOS) Static Transmission Services	The Wireless Beyond Line of Sight (BLOS) Static Transmission Services support wireless transfer of data amongst two or more static nodes Beyond Line of Sight (BLOS) of each other, employing modulated Radio Frequency (RF) carriers in different frequency bands.
2.3.3.7	Wireless Beyond Line of Sight (BLOS) Mobile Transmission Services	The Wireless Beyond Line of Sight (BLOS) Mobile Transmission Services support wireless transfer of data amongst two or more nodes, where one or more of the nodes are operating on the move, Beyond Line of Sight (BLOS) of each other, employing modulated Radio Frequency (RF) carriers in different frequency bands. Selection of frequency bands is based on coverage, capacity, propagation, transceiver attributes, and frequency coordination constraints.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	STO-TR-MSG-136-Part-IV AC/323(MSG-136)TP/831	ISBN 978-92-837-2157-4	PUBLIC RELEASE

5. Originator

Science and Technology Organization
North Atlantic Treaty Organization
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Modelling and Simulation as a Service
Volume 1: MSaaS Technical Reference Architecture

7. Presented at/Sponsored by

Developed by NATO MSG-136.

8. Author(s)/Editor(s)	9. Date
Multiple	May 2019

10. Author's/Editor's Address	11. Pages
Multiple	102

12. Distribution Statement

There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Cloud computing
Composability
Distributed simulation
Interoperability
Live, Virtual, Constructive (LVC) Modelling
Modelling and Simulation (M&S)
Modelling and Simulation as a Service (MSaaS)
M&S Services
NATO C3 Classification Taxonomy
Reference architecture
Service-Oriented Architecture (SOA)
Simulation
Simulation Architecture
Simulation Environments
Simulation Interoperability

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 provides the Allied Framework for Modelling and Simulation as a Service (MSaaS) Technical Reference Architecture. The aim of this document is to provide technical guidelines, recommended standards, architecture building blocks and architecture patterns that should be considered in realizing MSaaS capabilities. The Technical Reference Architecture uses the NATO C3 Classification Taxonomy as a tool for describing capability concepts and as a repository for architecture building blocks and patterns.

NORTH ATLANTIC TREATY ORGANIZATION

NATO OTAN

BP 25

F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE

Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

DIFFUSION DES PUBLICATIONS
STO NON CLASSIFIEES

Les publications de l'AGARD, de la RTO et de la STO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous. Si vous souhaitez recevoir toutes les publications de la STO, ou simplement celles qui concernent certains Panels, vous pouvez demander d'être inclus soit à titre personnel, soit au nom de votre organisation, sur la liste d'envoi.

Les publications de la STO, de la RTO et de l'AGARD sont également en vente auprès des agences de vente indiquées ci-dessous.

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivi du numéro de série. Des informations analogues, telles que le titre est la date de publication sont souhaitables.

Si vous souhaitez recevoir une notification électronique de la disponibilité des rapports de la STO au fur et à mesure de leur publication, vous pouvez consulter notre site Web (http://www.sto.nato.int/) et vous abonner à ce service.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7, D-53229 Bonn

BELGIQUE
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30, 1000 Bruxelles

BULGARIE
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DGSIST 2
Recherche et développement pour la défense Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

DANEMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESPAGNE
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

ESTONIE
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

ETATS-UNIS
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc
BP 72
92322 Châtillon Cedex

GRECE (Correspondant)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HONGRIE
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALIE
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
Voir Belgique

NORVEGE
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

PAYS-BAS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

POLOGNE
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

REPUBLIQUE TCHEQUE
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

ROUMANIE
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

ROYAUME-UNI
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down
Salisbury SP4 0JQ

SLOVAQUIE
Akadémia ozbrojených síl gen. M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 06 Liptovský Mikuláš 6

SLOVENIE
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

TURQUIE
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

AGENCES DE VENTE

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
ROYAUME-UNI

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivie du numéro de série (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Des références bibliographiques complètes ainsi que des résumés des publications STO, RTO et AGARD figurent dans le « NTIS Publications Database » (http://www.ntis.gov).

NORTH ATLANTIC TREATY ORGANIZATION

NATO OTAN

BP 25
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

DISTRIBUTION OF UNCLASSIFIED STO PUBLICATIONS

AGARD, RTO & STO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all STO reports, or just those relating to one or more specific STO Panels, they may be willing to include you (or your Organisation) in their distribution.

STO, RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable.

If you wish to receive electronic notification of STO reports as they are published, please visit our website (http://www.sto.nato.int/) from where you can register for this service.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30
1000 Brussels

BULGARIA
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DSTKIM 2
Defence Research and Development Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

CZECH REPUBLIC
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

DENMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESTONIA
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc – BP 72
92322 Châtillon Cedex

GERMANY
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7
D-53229 Bonn

GREECE (Point of Contact)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HUNGARY
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALY
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
See Belgium

NETHERLANDS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

NORWAY
Norwegian Defence Research Establishment, Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

POLAND
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

ROMANIA
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

SLOVAKIA
Akadémia ozbrojených síl gen M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 06 Liptovský Mikuláš 6

SLOVENIA
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

SPAIN
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

TURKEY
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

UNITED KINGDOM
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down, Salisbury SP4 0JQ

UNITED STATES
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

SALES AGENCIES

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
UNITED KINGDOM

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of STO, RTO and AGARD publications are given in "NTIS Publications Database" (http://www.ntis.gov).

ISBN 978-92-837-2157-4