MSG-168 Lecture Series on
Modelling and Simulation as a Service (MSaaS)

9. MSaaS Technical Reference Architecture

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ABSTRACT

The Allied Framework for Modeling and Simulation (M&S) as a Service (MSaaS) is proposed by NATO MSG-164 as a service- and cloud-based M&S ecosystem for use by NATO and partner nations. The framework is designed to aid stakeholders to utilize state-of-the-art service-oriented and cloud-based methodology and technology to achieve interoperability between participating simulation systems. This paper presents the reference architecture that is developed as part of the technical concept for the Allied Framework for MSaaS.

The structure of the MSaaS Technical Reference Architecture is supplied via the NATO C3 Taxonomy in the form of architecture building blocks and architecture patterns. The MSaaS Technical Reference Architecture is not a final product. It will change over time as new architecture building blocks and patterns are identified and added, and existing ones modified and improved.

1.0 INTRODUCTION

NATO and the nations use distributed simulation environments for various purposes, such as training, mission rehearsal and decision support in acquisition processes. Consequently, Modeling and Simulation (M&S) has become a critical technology for the coalition and its nations. However, achieving interoperability between participating simulation systems and ensuring credibility of results still requires large expenditures with regards to time, personnel and budget.

Recent technical development in cloud computing technology and service-oriented architecture (SOA) offers opportunities to utilize M&S capabilities better in order to satisfy NATO critical needs. A new concept that includes service orientation and the provision of M&S applications via the as-a-service model of cloud computing may enable composable simulation environments that can be deployed rapidly and on-demand. This new concept is known as M&S as a Service (MSaaS).

NATO MSG-164 investigates MSaaS with the aim of providing the technical and organizational foundations for a future permanent service-based M&S ecosystem within NATO and partner nations, called the Allied Framework for MSaaS.

This paper presents the MSaaS Technical Reference Architecture, which is part of the technical concept for the Allied Framework for MSaaS [1].

2.0 MSAAS VISION

The vision of MSaaS within NATO context is to establish an MSaaS ecosystem, where MSaaS Capabilities from different nations are federated, see Figure 1. An MSaaS ecosystem is a network of organizations with MSaaS Capabilities that drives the creation, delivery and use of M&S services in NATO context. An MSaaS Capability consists of operational capabilities as well as technical capabilities needed to achieve this.

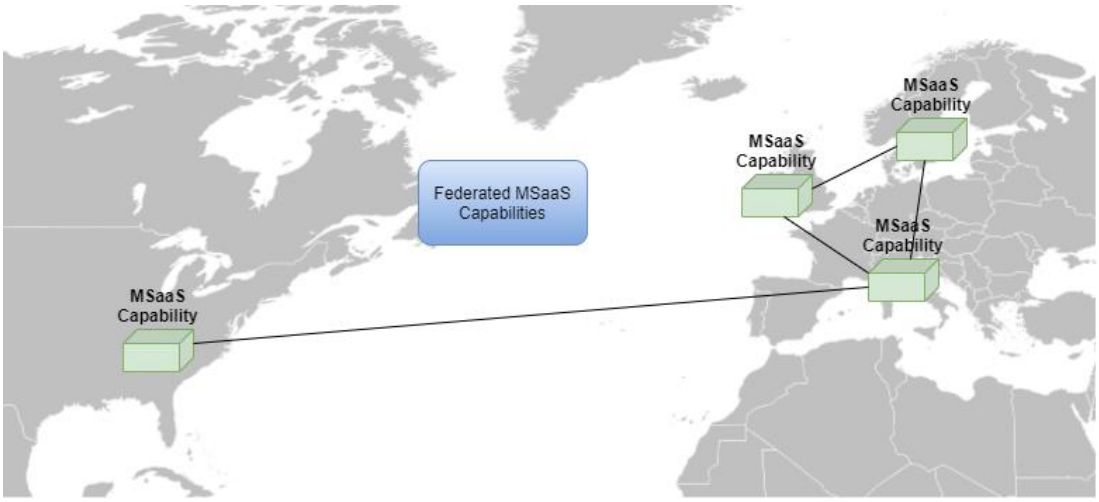


Figure 1: Notional MSaaS ecosystem consisting of federated National and NATO MSaaS Capabilities.

The operational capabilities consist of a *Concept of Employment*, a *Business Model*, and technical *M&S Engineering Processes*. The Concept of Employment provides the recommended operating procedures and technical references to promote M&S service sharing and interoperability between MSaaS Capabilities. The Business Model informs relevant stakeholders on how the MSaaS ecosystem will operate in the multi-government business space for the sharing of M&S technologies and services. And the M&S Engineering Processes inform organizations on the engineering activities required for development and use of services and compositions of services within an MSaaS Capability.

The *Concept of Employment*, the *Business Model* and the *M&S Engineering Processes* are addressed in other presentations of this Lecture Series. The technical capabilities to support the creation, delivery and use of M&S services in the form of Architecture Building Blocks organized in a Technical Reference Architecture, are the topic of this paper.

3.0 MSAAS ARCHITECTURE FRAMEWORK

Architectures can be designed at various levels of abstraction and different types of architecture can be distinguished. There is little consensus in general on the various levels of abstraction or on how to name them. For instance NATO Architecture Framework (NAF) version 4 mentions different kinds of architecture and the activities leading to these architectures. The different kinds or types of architecture are shown in Figure 2,

The architectures are:

- **Enterprise Architectures** are developed by the enterprise tier activities,

- **Reference architectures** are developed by domain and programme tier activities, and
- **Project architectures** are developed by project tier activities.

The type **Reference Architecture** is the focus of this document.

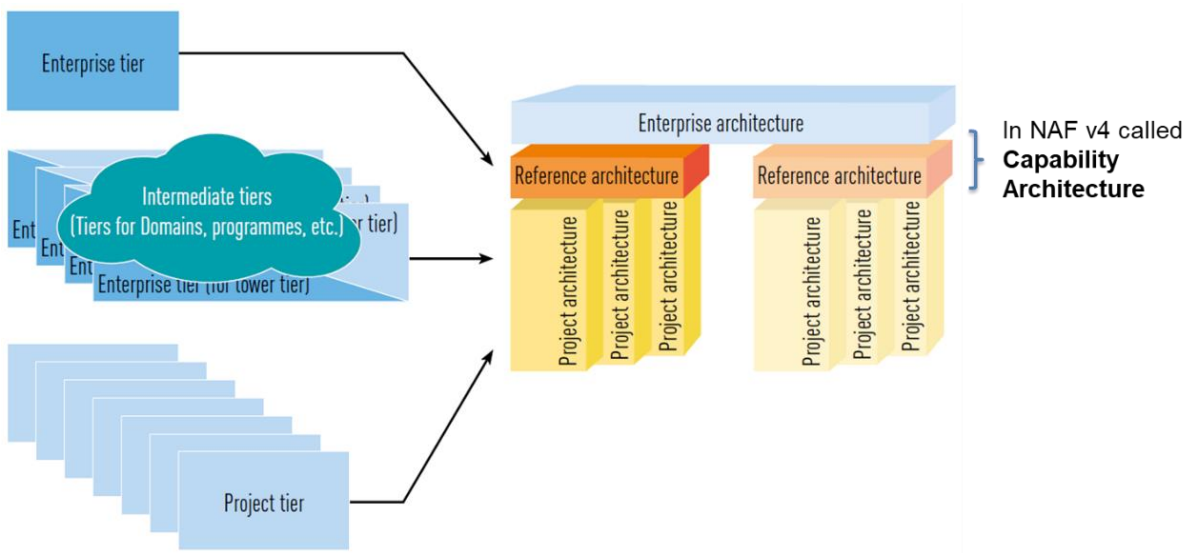


Figure 2: Architecture types.

The various kinds of architecture have different stakeholders and users, and **methods** need to be applied for refining an architecture at one abstraction level to the next. The spectrum of architecture abstraction levels and such methods are what we here refer to as an **architecture framework**. The architecture framework for MSaaS is shown in Figure 3.

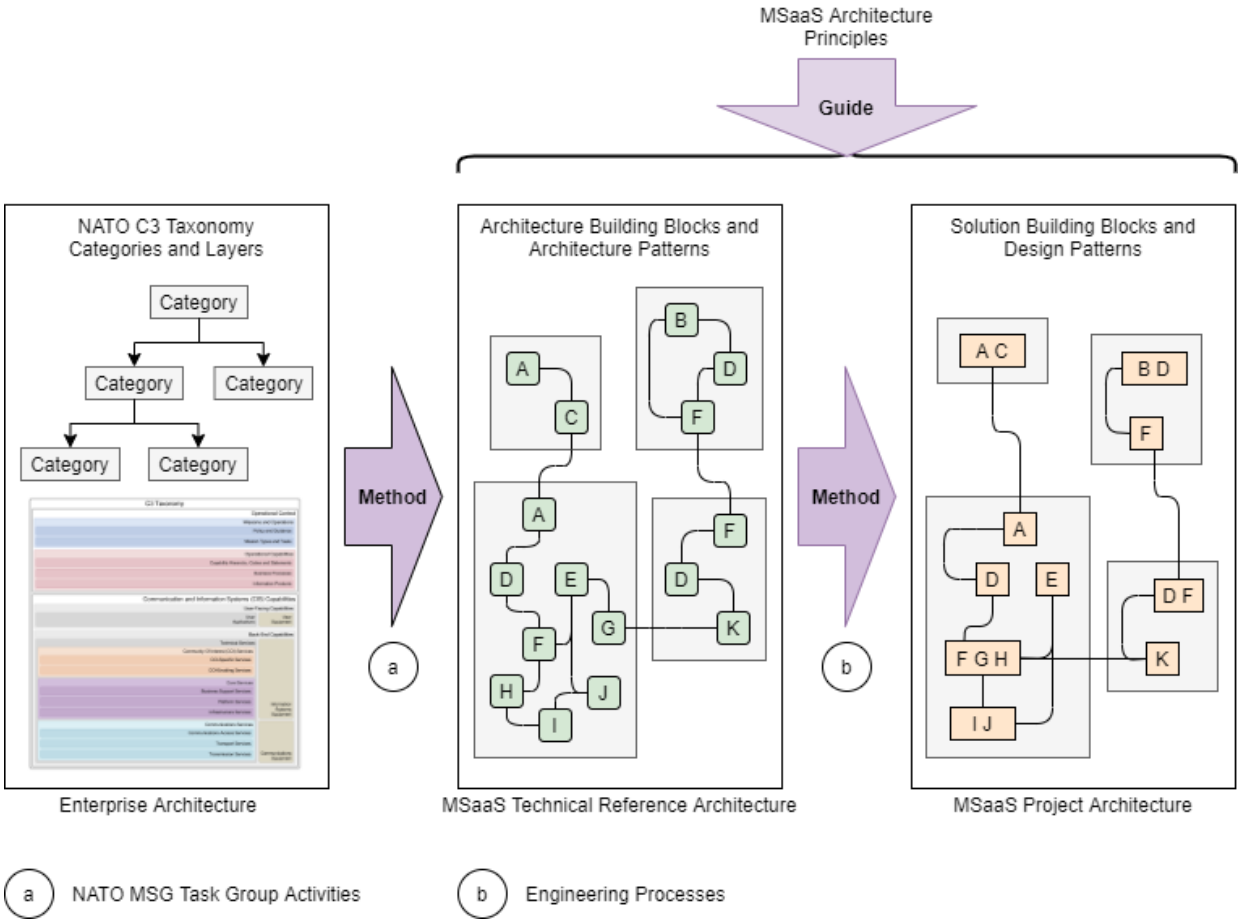


Figure 3: MSaaS Architecture Framework.

The NATO Consultation, Command and Control (C3) Taxonomy is considered as the **Enterprise Architecture**. The NATO C3 Taxonomy provides a categorization of NATO C3 capabilities (including standards and requirements), organised in a hierarchy by supertype-subtype relationships. The taxonomy is developed and maintained by NATO ACT and can be viewed and modified through the C3 Taxonomy's Enterprise Management Wiki site

The MSaaS **Technical Reference Architecture** (TRA) is developed and maintained under the umbrella of the NMSG through Task Groups. The TRA defines the **architecture building blocks** that should be considered for the realisation of an **MSaaS Capability**. This concerns both process building blocks as well as technical building blocks. The notions **Architecture Building Block** (ABB) and **Architecture Pattern** (AP) are used to describe building blocks and to describe how building blocks may be combined. Note that the architecture building blocks in this type of architecture *define capabilities.*

The architecture of a specific MSaaS Capability is called a **Project Architecture** (also called solution architecture). Since the MSaaS TRA provides the architecture building blocks for an MSaaS Capability, many of the requirements for the solution building blocks used in the project architecture can in principle be derived from the building blocks in the TRA. Still, refinement is generally needed to meet the requirements and constraints of the project. Note that the solution building blocks in this type of architecture *define a solution.*

4.0 ENTERPRISE ARCHITECTURE

The NATO Consultation, Command and Control (C3) Taxonomy (Figure 4) is viewed as the Enterprise Architecture. In this slide this is illustrated with an image of the taxonomy map, and the hierarchy of categories. The NATO C3 Taxonomy provides a categorization of NATO C3 capabilities (including standards and requirements), organised in a hierarchy by supertype-subtype relationships. The taxonomy is developed and maintained by NATO ACT and can be viewed and modified through the C3 Taxonomy's Enterprise Management Wiki site. [2].

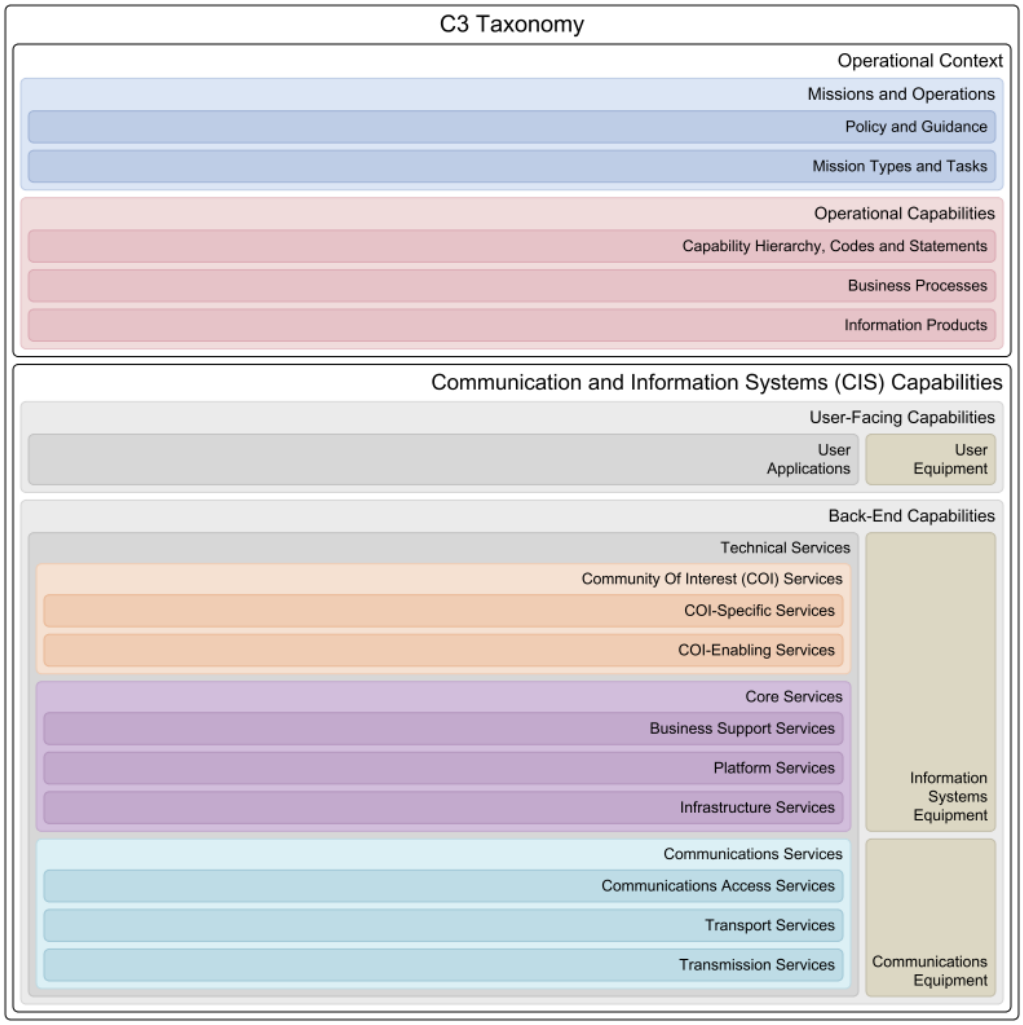
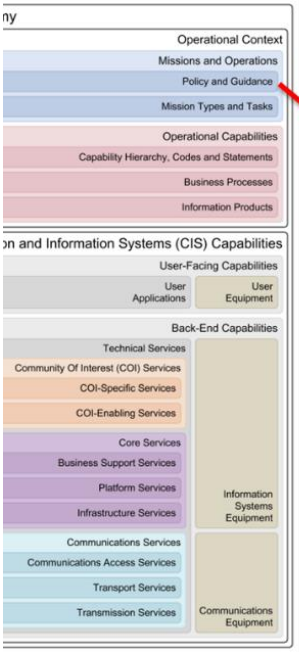


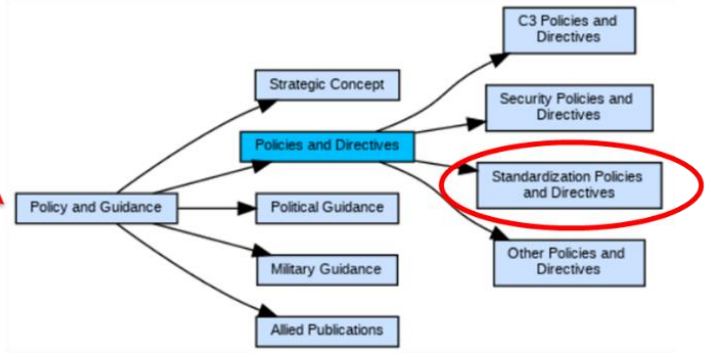
Figure 4: NATO C3 Taxonomy.

The following figures provide examples of some relevant parts of the C3 Taxonomy.

Standardization Policies and Directives

This category lists policies, including M&S policies; future MSaaS policies will appear here too.

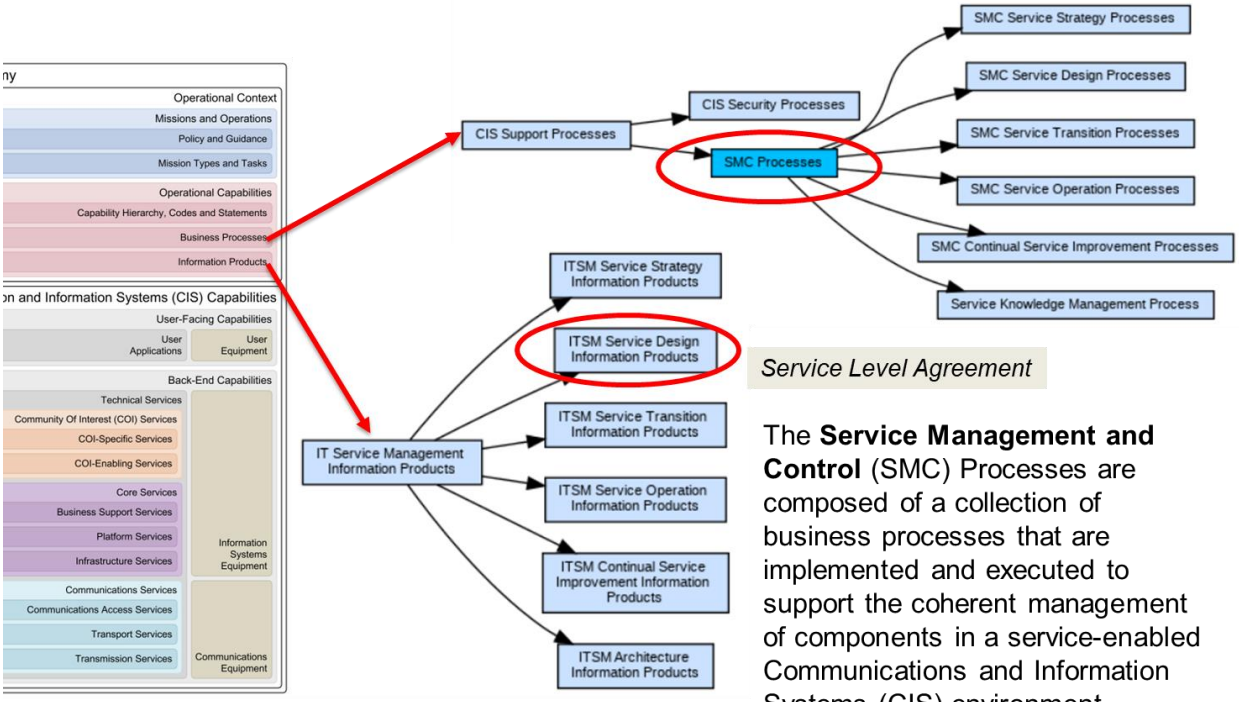




Standardization Policies and Directives for M&S:
- Allied Publications: AMSP-01 (NATO M&S Standards Profile)

Service Management and Control Processes and IT Service Management Information Products

These categories are relevant for MSaaS Customer and Supplier management, and service level agreements.

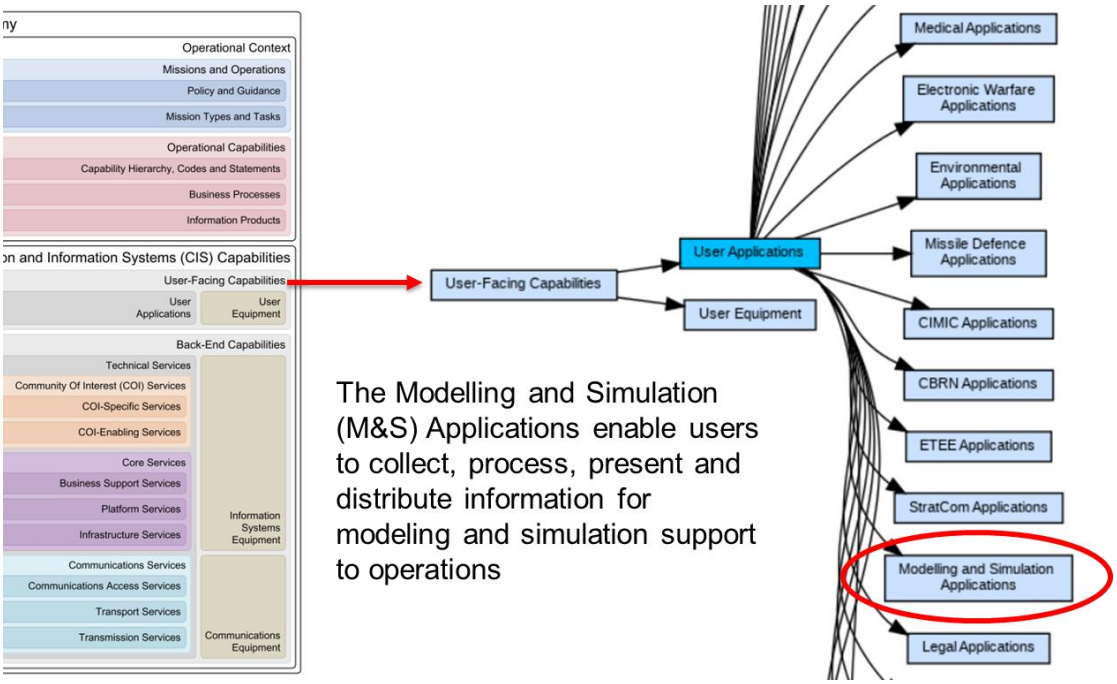


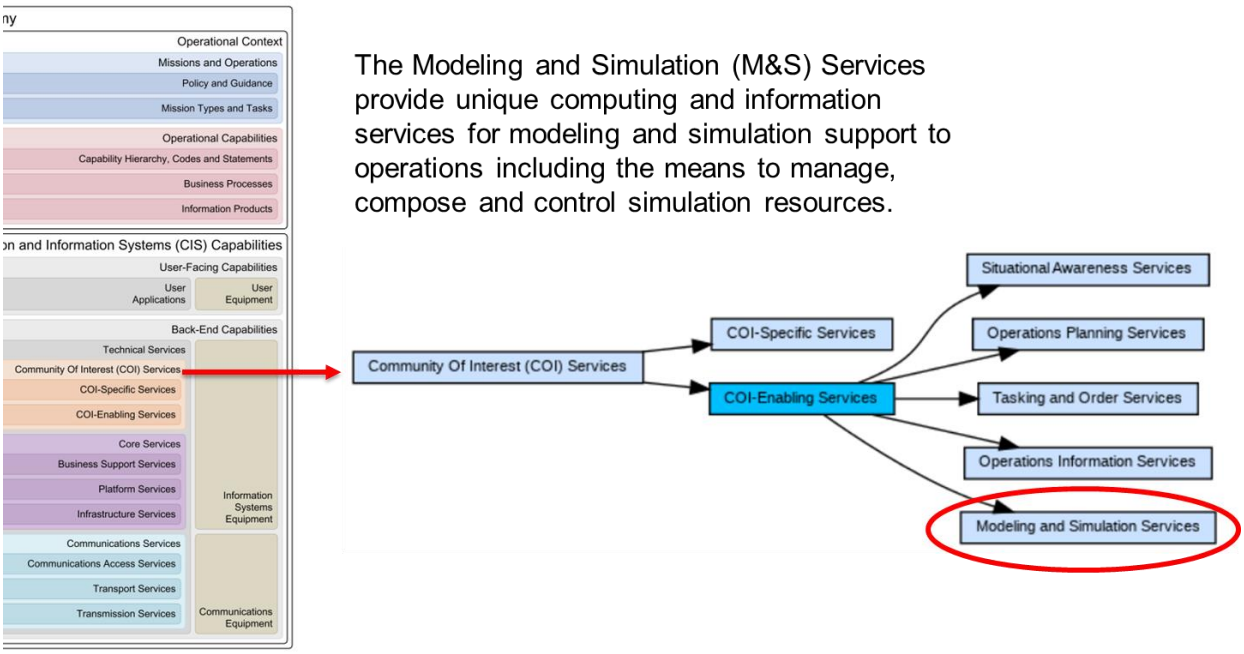
Service Level Agreement

The **Service Management and Control** (SMC) Processes are composed of a collection of business processes that are implemented and executed to support the coherent management of components in a service-enabled Communications and Information Systems (CIS) environment.

Modelling and Simulation Applications, and Modelling and Simulation Services

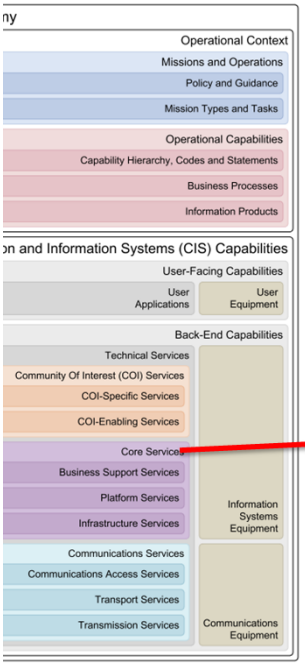
These categories list M&S capabilities.





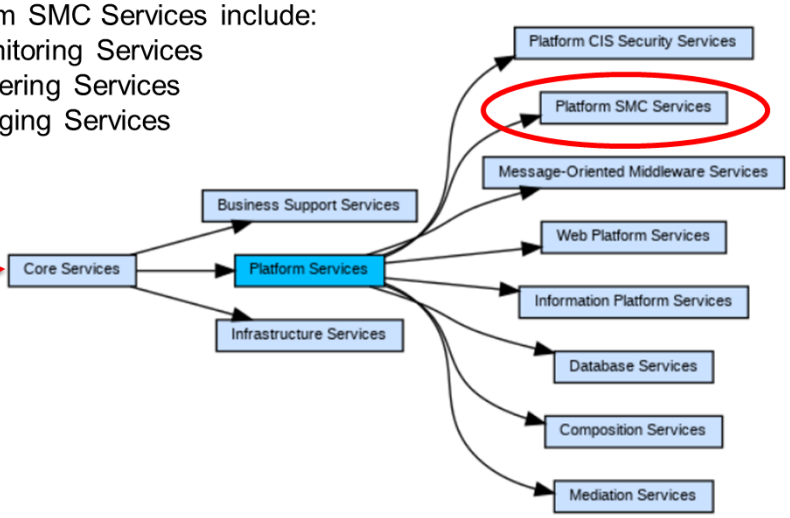
Platform SMC Services

These categories lists general platform capabilities, on which to deploy Simulation Services.



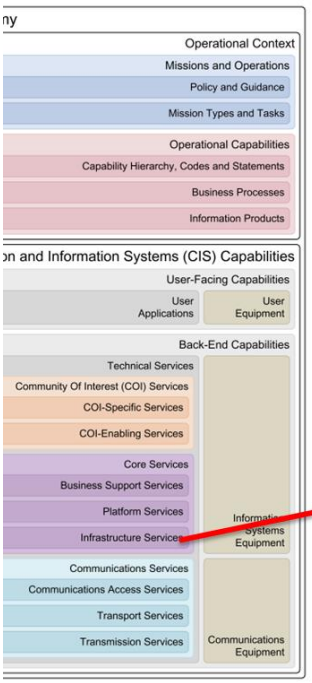
The Platform Service Management and Control (SMC) Services provide a suite of capabilities needed to ensure that platform services are up and running.

Platform SMC Services include:
- Monitoring Services
- Metering Services
- Logging Services

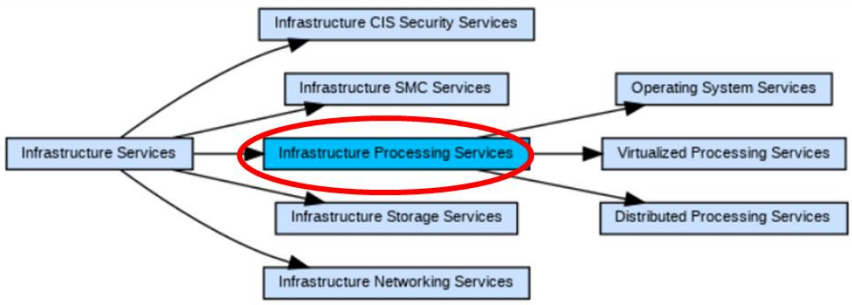


Infrastructure Processing Services

There categories list infrastructure capabilities, required to have a platform on which to deploy services.



The Infrastructure Processing Services provide shared access to physical and/or virtual computing resources.



5.0 REFERENCE ARCHITECTURE

5.1 ARCHITECTURE PRINCIPLES

Principles are general rules and guidelines, intended to be enduring and seldom amended, that inform and support the way in which an organization (i.e. NATO and its nations) sets about fulfilling its mission [3].

Architecture principles are a set of principles that relate to architecture work. They reflect a level of consensus across the enterprise, and embody the spirit and thinking of existing enterprise principles. Architecture principles govern the architecture process, affecting (informing, constraining) the development, maintenance, and use of the enterprise architecture, in this case the MSaaS Technical Reference Architecture

It is common to have sets of principles form a hierarchy, in that architecture principles will be informed by, elaborated on and constrained by enterprise principles. Architecture principles define the underlying general rules and guidelines for the use and deployment of resources and assets. They reflect a level of consensus among the various elements of the enterprise, and form the basis for making future decisions. Each architecture principle should be clearly related to the operational objectives and key architecture drivers [3].

Attributes of archtecture princples include:

- **Name**: states the essence
- **Statement**: describes the fundamental rule
- **Rationale**: why?
- **Implications**: highlight the requirements, both for the business and IT, for carrying out the principle

Principles include the following statements:

- *MSaaS facilitates simulation service composability*
- *MSaaS facilitates simulation service interoperability*
- *MSaaS facilitates simulation resource pooling*
- *MSaaS complies with NATO policies and standards*

5.2 USE CASES

Use cases are used to identify required capabilities for the Technical Reference Architecture.

Recall the main MSaaS use case actors:

Customer: The Customer is the acquirer of M&S services, for example a defense organization with an operational need (e.g., training, mission planning, acquisition), and is the budget holder.

Provider: The Provider makes M&S services available to Users of the Allied Framework for MSaaS in accordance with Customer SLAs. The Provider has the responsibility for the composition and integration of M&S services in accordance with Customer requirements.

User: The User is the consumer of M&S services.

Supplier: The Supplier supplies M&S services to the Provider as part of the Allied Framework for MSaaS, for example via a procurement or a license agreement. Examples of Suppliers include large defense contractors, small and medium enterprises, and academic institutions, in addition to government organizations.

The Provider is divided in several sub-actors, as shown in Figure 5.

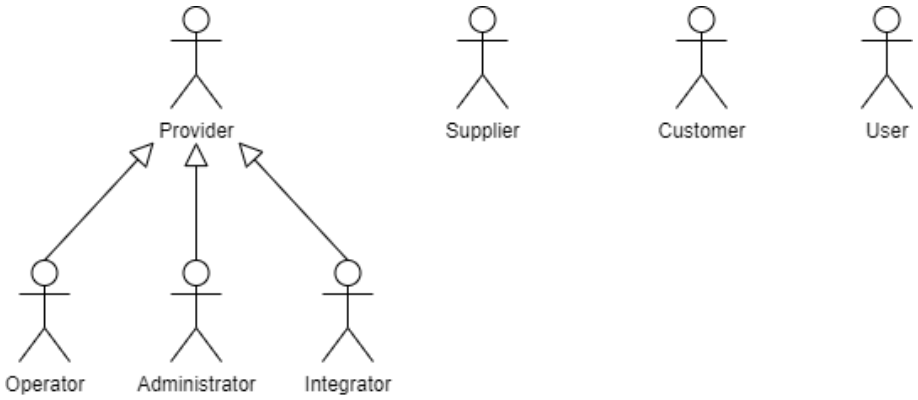


Figure 5: MSaaS main actors.

Provider > Operator: The Operator ensures a correctly functioning simulation deployment in the MSaaS Capability.

Provider > Integrator: The Integrator develops compositions from available M&S services, to be used by the Operator.

Provider > Administrator: The Administrator maintains the MSaaS Capability

An overview of the use cases is shown in Figure 6.

Figure 6: MSaaS use cases.

5.3 BUILDING BLOCKS

The notion **Architecture Building Block** (ABB) is used to describe the building blocks in the MSaaS Technical Reference Architecture. A similar notion **Solution Building Block** (SBB) is used to refer to the elements in the Project Architecture. These notions are derived from TOGAF, see Figure 7.

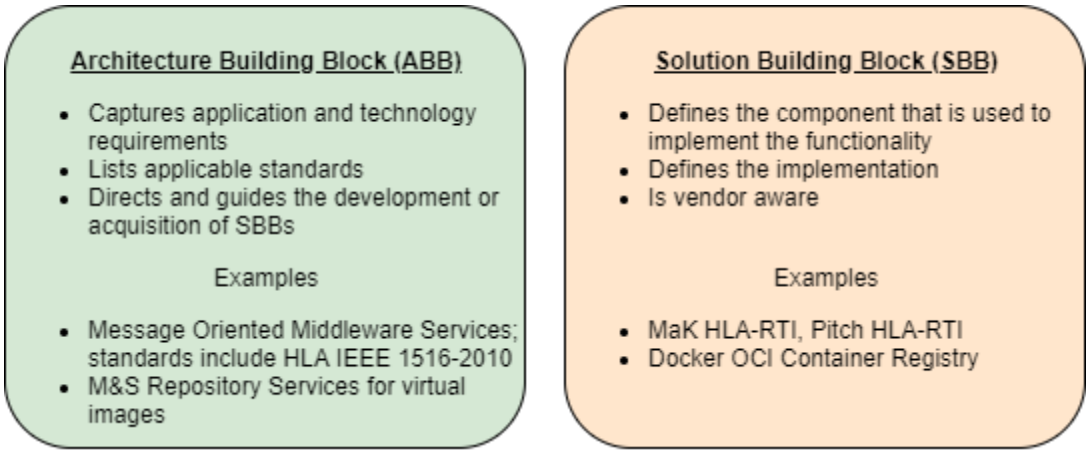


Figure 7: Architecture Building Block and Solution Building Block.

An ABB defines a **capability to support the use cases** in terms of requirements and standards, whereas an SBB specifies a **solution** that conforms to the requirements of the related ABB. An ABB represents a component of the Technical Reference Architecture and describes a logical aspect of the overall architecture.

An example of an Architecture Building Block and an Architecture Pattern is provided below, see Figure 8.

- The **Scenario Distribution Services** is an ABB (within a larger set of ABBs) that provides the means to distribute ORBAT data within a simulation. For this capability several functional requirements are listed in the table. Applicable standards (not listed) include SISO MSDL and SISO C2SIM.

- The AP pictured shows one way (of several) of combining this capability with other capabilities. In this example ORBAT data can be pushed from Scenario Distribution Services, or pulled by Simulation Services.

Important to emphasize again is that the ABB defines a capability in terms of requiremens and standards. It does not state how it should be implemented. Implementation considerations are for the Project Architecture, such as an ORBAT Server from company X.

Function Name	**Requirement**
Provide ORBAT	Scenario Distribution Services shall provide the means for clients to either push or pull scenario data.
Publish ORBAT	Scenario Distribution Services shall provide the means to publish the scenario data in the simulation environment.
Update ORBAT	Scenario Distribution Services shall provide the means to update the scenario in the simulation environment; this concerns the addition, deletion and updating of scenario elements.
Delete ORBAT	Scenario Distribution Services shall provide the means to remove the scenario from the simulation environment.
Take snapshot	Scenario Distribution Services shall provide the means to update previously provided scenario data with the current state in the simulation environment.

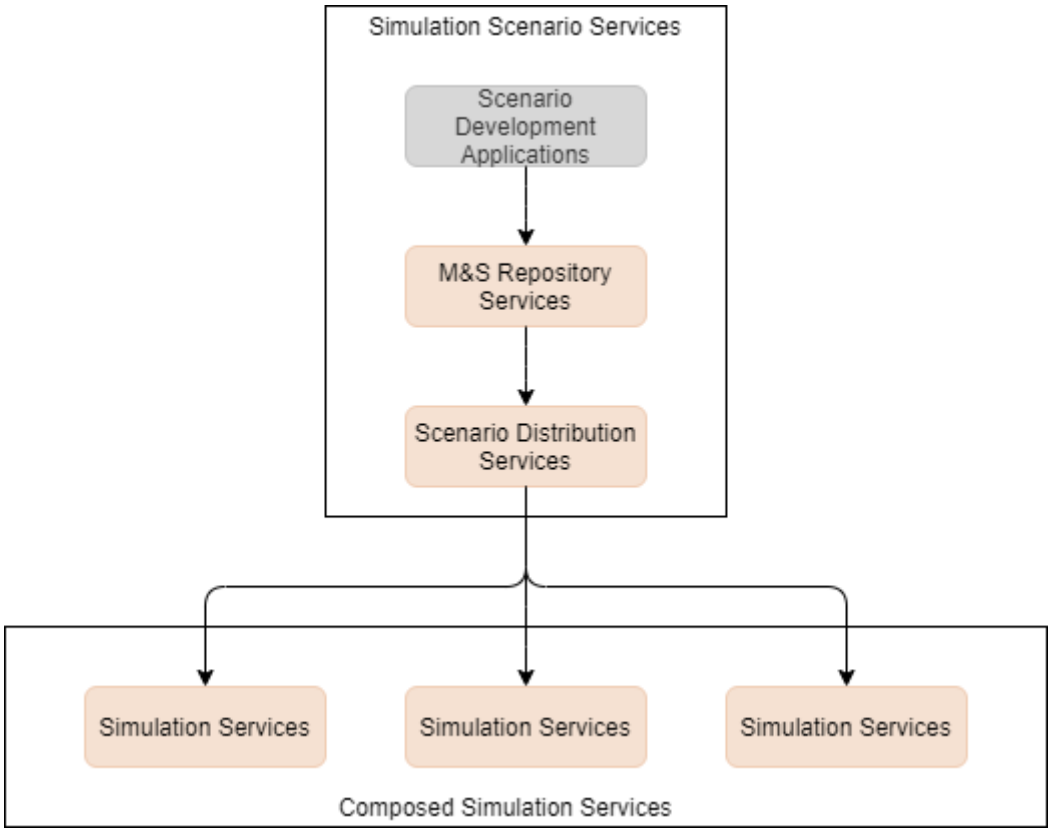


Figure 8: Example of an Architecture Pattern for Scenario Distribution.

5.4 MSAAS CAPABILITY: CLUSTERING OF BUILDING BLOCKS

Following is an overview of the main ABB clusters of the MSaaS Capability, organized in line with the main categories of the NATO C3 Taxonomy (see Figure 9):

- **Operational Capabilities**: the Concept of Employment, Business Model, and the M&S Engineering Processes. The Concept of Employment and Business Model are discussed in other presentations. The M&S Engineering Processes cover the activities to engineer composed simulation services within an existing MSaaS Capability. The processes make use of the User-Facing and Back-End Capabilities.

- **User-Facing Capabilities**: M&S Portal Applications as well as the M&S User Applications. These are applications that users interact with, hence are called “User-Facing”.

- **Back-End Capabilities**: several building blocks to support the User-Facing Capabilities. M&S Enabling Services provide, amongst other, the capabilities to store, retrieve and manage M&S Resources and the associated metadata.

- **Core Services and Communication Services**: general capabilities that need to be in place for any MSaaS implementation.

- **Communications and Information Systems (CIS) Security**: a cross-cutting cluster and defines capabilities related to security.

- **Service Management and Control (SMC**): defines a collection of building blocks to coherently manage components in a federated infrastructure.

The MSaaS Technical Reference Architecture covers the the User-Facing Capabilities and Back-End Capabilities, and the technical parts of the cross-cutting capabilities. Each of these capabiliries is subdivided in several smaller sub-capabilities.

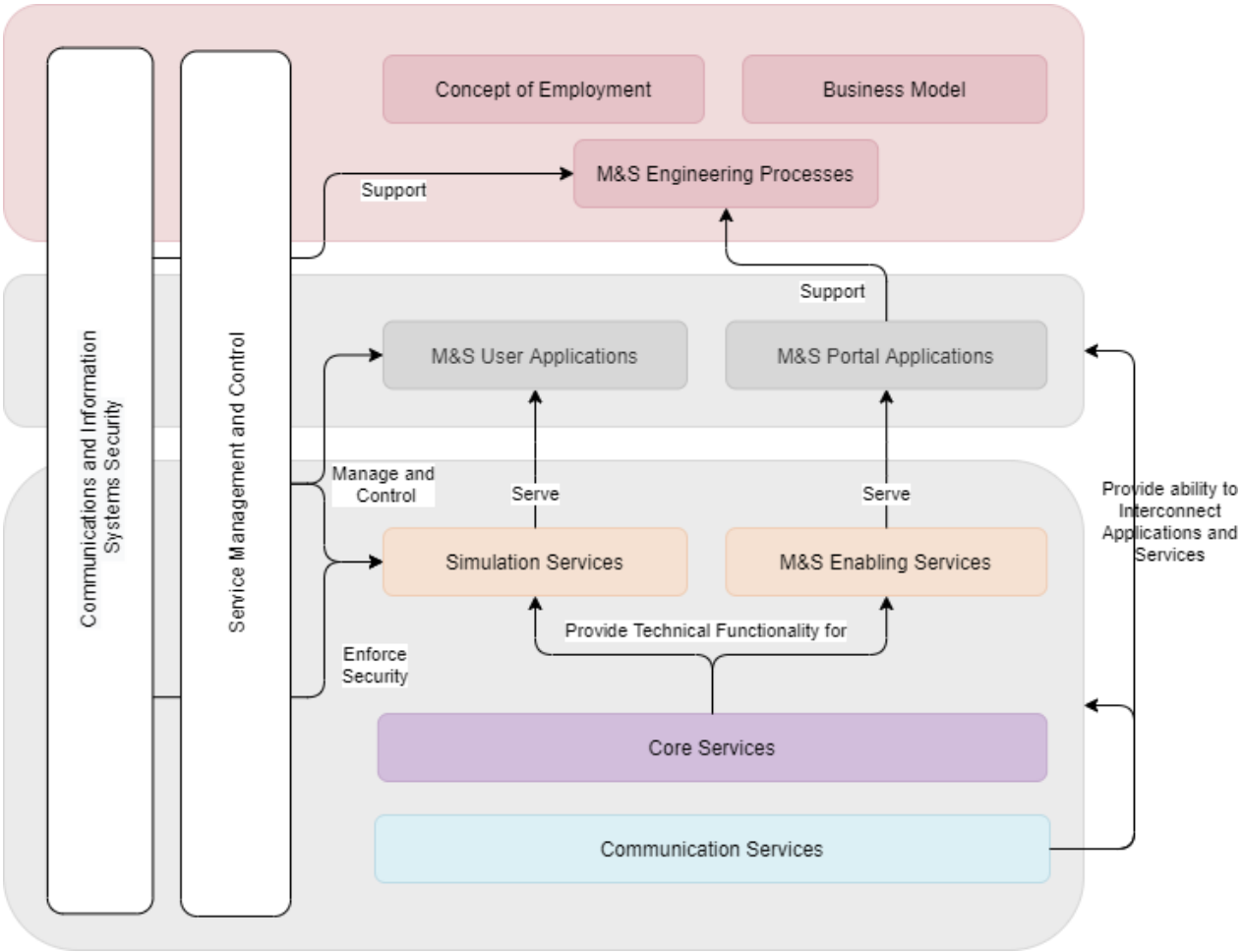


Figure 9: MSaaS Capability: Clustering of Building Blocks.

5.4.1 M&S PORTAL APPLICATIONS AND M&S ENABLING SERVICES

M&S Portal Applications and **M&S Enabling Services** define capabilities that *enable* the discovery, composition and execution of Simulation Services and M&S User Applications in an MSaaS Capability.

Portal and Enabling Services capabilities include:

- Integrator Portal Applications (for creating compositions and deployment descriptions)
- Supplier Portal Applications (for providing M&S Resources and associated metadata)
- M&S Repository Services (for managing and exchanging M&S Resources)

- M&S Registry Services (for managing and exchanging M&S Resource Metadata)
- M&S Message Oriented Middleware (MOM) Services (for distributing simulation data) and M&S Mediation Services (for connecting external services and applications)
- Simulation Scenario Services (for managing simulation scenarios)

5.4.2 M&S USER APPLICATIONS AND SIMULATION SERVICES

M&S User Applications and **Simulation Services** define capabilities for the synthetic representation of (real-world) objects and events:

- For these there are many !

Solutions for Simulation Services are provided by Suppliers in the form of virtual images (Virtual Machine image, Container image) or datasets, and stored by M&S Repository Services, ready for deployment within the MSaaS Capability.

Following are just a few examples of Simulation Services for which one or more implementations can be provided. These capabilities can be linked to categories in the C3 Taxonomy. Recall that the term "Simulation Services" concerns an ABB and refers to a capability. The term does not refer to a solution or a software implementation.

- Route Planning Services
- Weapon Effects Services
- Tactical Data Link Services
- Radio Communication Services
- Cyber Effects Services
- Electronic Warfare Services
- Vantage Point Services
- Track Generation Services
- Platform Generation Services
- Meteo Services

The description (or the content) of the ABB for Simulation Services includes the following [4], see Figure 10:

<u>For the Supplier</u>

- requirements or specifications, for the benefit of the supplier who will realize the service as an executable software implementation, supplied in the form of a virtual image.

For the Integrator

- an interface with functional and operational signatures for syntactic interoperability;
- a contract with elaborations of what the functions; and operations declared in the interface do in terms of functional and operational semantics, for a degree of semantic interoperability, as well as a specification of contractual nonfunctional requirements;
- a model for simulation services of that which is being simulated in the form of limited information (white-box view) on internal workings of the simulation functionality provided by the simulation service, necessary for determining what assumptions in the environment the simulation service uses, for pragmatic interoperability.

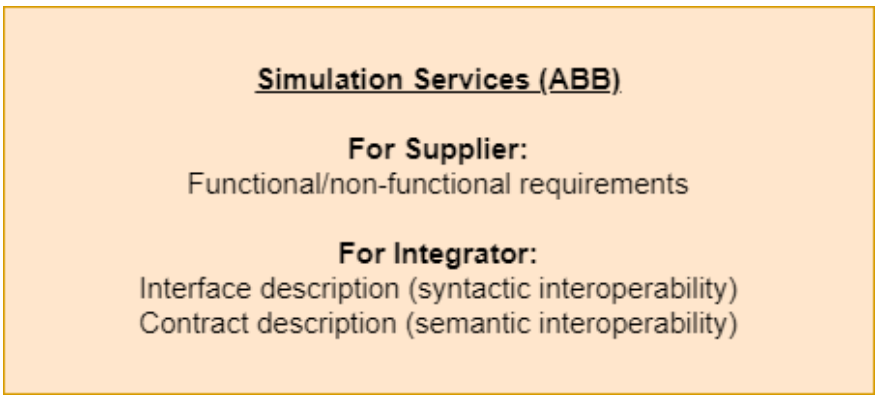


Figure 10: Content of the ABB for Simulation Services.

The Technical Reference Architecture uses the NATO C3 Taxonomy as a dynamic catalog for the categorization of Simulation Services. The number of conceivable Simulation Services is unlimited.

5.5 FEDERATING MSAAS CAPABILITIES

MSaaS Capabilities are federated to form an MSaaS ecosystem, with the aim to share M&S Resource Metadata, share M&S Resources, and connect Simulation Services for performing a federated simulation. Different levels at which MSaaS Capabilities can be federated are discussed below.

Note that the actual sharing of data is generally subjected to security policies and the classification of data involved, to name a few. MSaaS Implementations may typically share data on a per project/agreement basis, rather than via an Community of Interest MSaaS ecosystem.

Level 0 - standalone

This level indicates a stand-alone MSaaS Capability, i.e. there is no interoperability with other MSaaS Capabilities. For example, the MSaaS Capabilty resides on a national and restricted network. At this level the MSaaS Capability only provides Simulation Services to the national User.

Level 1 – ability to participate in a common simulation environment

At this level the MSaaS Capability has the ability to provide Simulation Services to and consume Simulation Services from another MSaaS Capability. The MSaaS Capability has the ability to participate in a federated

simulation environment, such as an HLA federation.

Figure 11 illustrates this level. The different MSaaS Capabilities are connected through Communication Services that provide the ability to securely transmit and receive data, such as a dedicated VPN or a CFBL-Net enclave. M&S Message Oriented Middleware (MOM) Services (e.g. HLA RTI) and M&S Mediation Services (e.g. Pitch Booster, WebLVC Server) may be used to enable the exchange of simulation data between MSaaS Capabilities, via the Communication Services.

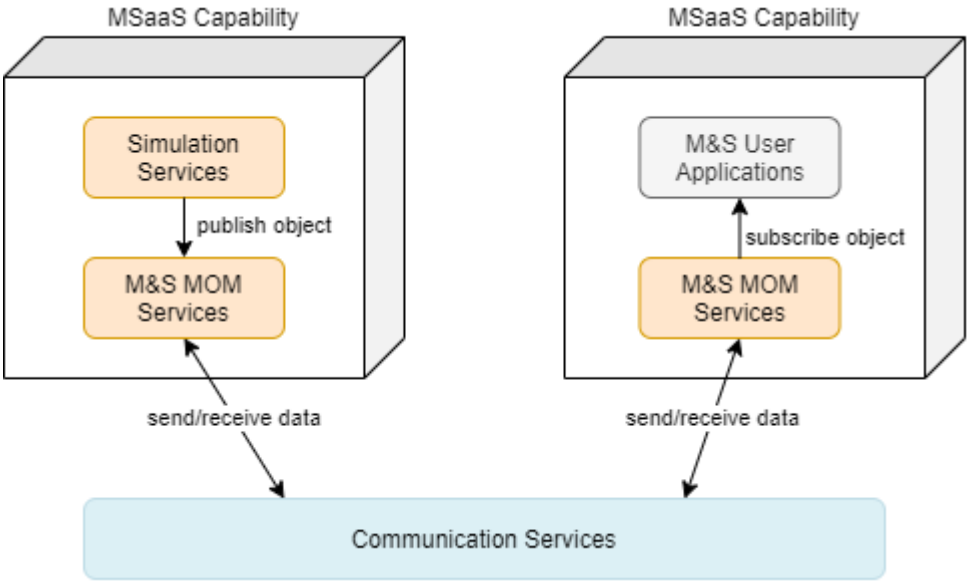


Figure 11: Pattern for connecting Simulation Services between MSaaS Capabilities.

Level 2 – ability to exchange metadata

This level is broken out in several sub-levels of interoperability.

Level 2A – ability to exchange M&S Resource Metadata

At this level the MSaaS Capability has the ability to interact with another MSaaS Capability with respect to the discovery of M&S Resources and the exchange of M&S Resource Metadata. This requires that the MSaaS Capability realizes for instance the M&S Registry Services.

Figure 12 shows two MSaaS Capabilities with M&S Registry Services that provide the ability to push or pull M&S Resource Metadata. A standard (under development) to be considered for the exchange of metadata is the Discovery Metadata Specification for M&S Resources [5]. The Communication Services (e.g. provided by VPN or CFBL-Net) have not been included in order to simpify the figure.

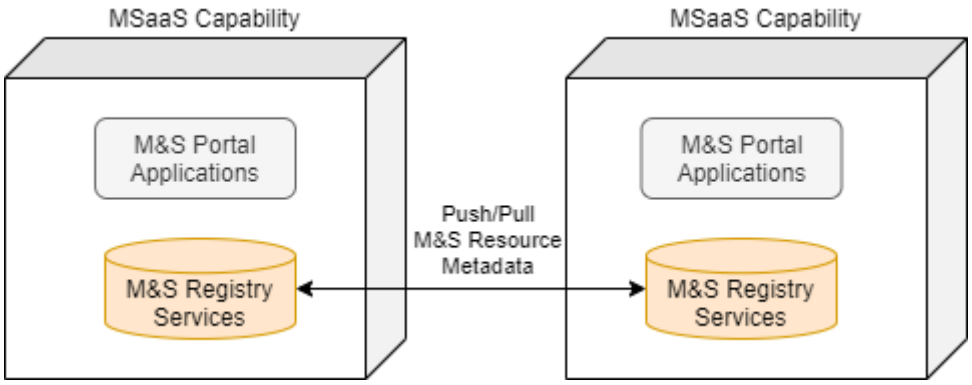


Figure 12: Pattern for the exchange of M&S Resource Metadata.

Level 2B – ability to exchange M&S Resources

At this level the MSaaS Capabilty has the ability to retrieve M&S Resources from another MSaaS Capability or provide an M&S Resources to another MSaaS Capability. M&S Resources are for example Docker container images or VM images. This requires that the MSaaS Capability realizes the M&S Repository Services.

Figure 13 shows two MSaaS Capabilities, where one has the ability to pull M&S Reources from the second. M&S Resources are typically associated with the M&S Resource Metadata, such as a virtual image that contains the service implementation. Again, the Communication Services are left out of the figure.

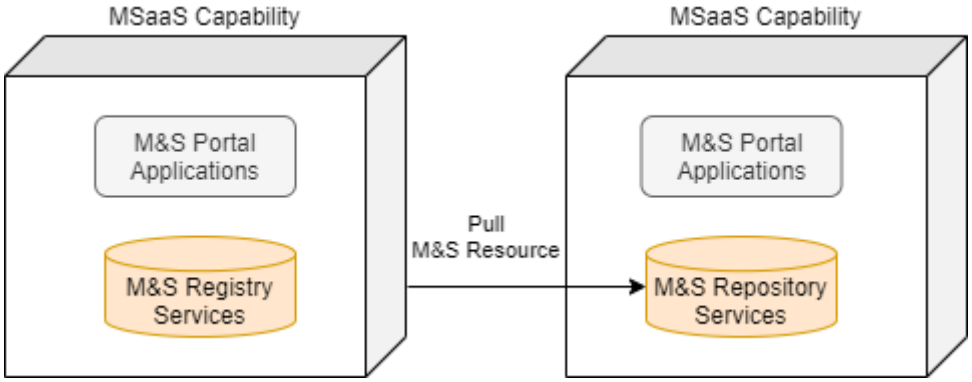


Figure 13: Pattern for the exchange of M&S Resources.

Level 2C – ability to exchange composition and deployment descriptions

At this level the MSaaS Capability has the ability to share composition and deployment descriptions with another MSaaS Capability. I.e. the two MSaaS Capabilities share a common model for the composition and deployment of simulation services. See Figure 14.

This level requires that the MSaaS Capability realizes the M&S Registry Services and M&S Repository Services. In addition the assumption is that the deployment descriptions can be consumed by the receiving technology platform. For example, both capabilities are implemented with Kubernetes, using Helm Charts [5] as deployment descriptions. M&S Repository Services for Helm Charts are implemented using a Helm Chart Repository such as the Artifact Hub [6].

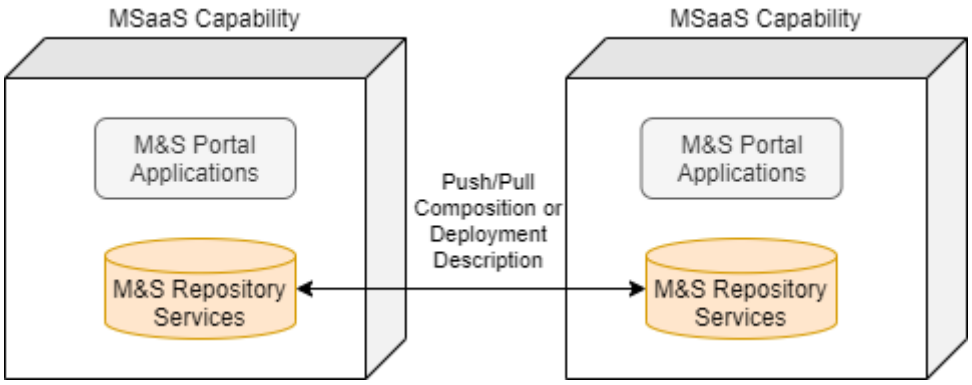


Figure 14: Pattern for the exchange of Composition and Deployment Descriptions.

Level 2D – ability to exchange service management and control data

At this level the MSaaS Capability has the ability interact with another MSaaS Capabity w.r.t. the exchange of Service Management and Control (SMC) data. This concerns monitoring, metering and logging data, as well as data to manage the deployment, execution, and termination of services. This requires that the MSaaS Capability realizes the SMC Services. Figure 15 provides an example for the exchange of metrcis data.

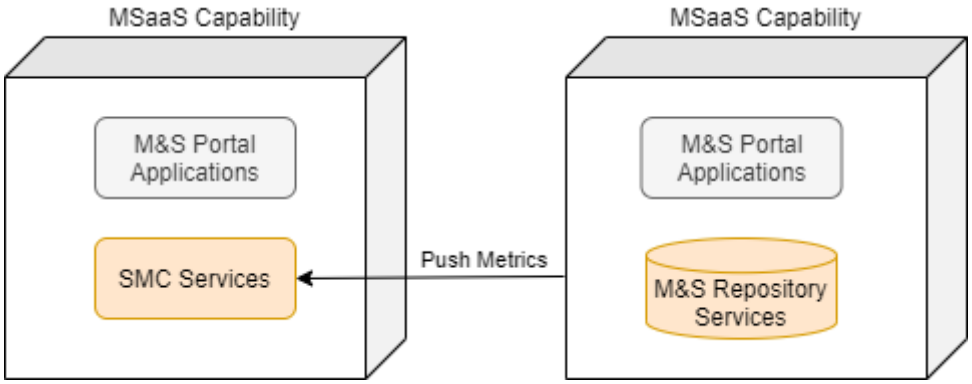


Figure 15: Pattern for the exchange of metrics between MSaaS Capabilities.

6.0 PROJECT ARCHITECTURE

The architecture of a specific implementation of an MSaaS Capability is called a Project Architecture (also called solution architecture). Since the MSaaS Technical Reference Architecture provides the building blocks, many of the requirements for the solution building blocks used in the Project Architecture can (and should!) in principle be derived from the building blocks in the Technical Reference Architecture. Still, refinement is generally needed to meet the specific requirements and constraints of the project.

Generally, when developing a solution, decisions need to be made about the nature of the solution including:

- Specying the requirements for the solution
- Building vs buying a solution
- Selecting the appropriate technology platform

- Prototyping the solution
- Deployment of the solution

Thus different Project Architectures and solutions may be derived from the MSaaS Technical Reference Architecture.

In MSG-136 and MSG-164 experimentation was performed with the following technology platforms:

- Thales NUADA (commercial)
- Leonardo OCEAN (commercial)
- Kubernetes (open source)

All providing the capabilities described in the Technical Reference Architecture to some extent.

7.0 SUMMARY AND CONCLUSIONS

We have outlined the MSaaS Technical Reference Architecture as part of an architecture framework for MSaaS. The purpose of the MSaaS Technical 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 Technical Reference Architecture as the demand for M&S capabilities increases and shifts.

The framework in this paper lays the ground for the substantial and hard tasks of determining how functionality should be divided into loosely coupled M&S capabilities (services and applications), for writing the corresponding Simulation Services capability descriptions (interfaces and contracts) and functional and non-functional requirements, and for developing architecture patterns.

The MSaaS Technical Reference Architecture – with its link to the C3 Taxonomy – can help maintain an updated view on which building blocks and patterns are present and which are lacking in relation to the current state of research and development in NATO's C3 systems portfolio, and can help to identify where further technology or standards development should take place.

8.0 ACKNOWLEDGEMENTS

The author would like to acknowledge to contribution of MSG-164 for defining the reference architecture described in this paper.

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