Towards a NATO Reference Architecture for Joint Mission Training Through Distributed Simulation

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ABSTRACT

NATO and nations face an urgent need for combined and joint collective training to ensure mission readiness: current and future operations are multinational in nature, missions and systems are becoming more complex and need detailed preparation and rapid adaptation to changing circumstances. The opportunities for live training and mission preparation in a multinational context are reduced due to fewer available resources, limited training ranges, the challenges to prevent opponents from observing 5th gen tactics and system capabilities and limited preparation time between political decision making and deployment. Simulation has become an essential tool in addressing the training demands of our military forces and nations are moving towards adopting national Mission Training through Distributed Simulation (MTDS) capabilities. The coalition forces are looking for a new balance between live- and simulated training and exercising that provides the best of both worlds.

Several NATO Modelling & Simulation Group (NMSG) initiatives have contributed valuable inputs for the development of a NATO MTDS vision and concept of operations (MSG-106 NETN, MSG-128 MTDS, MSG-169 LVC-T). Building on these results, current/recent NMSG activities (MSG-163 Evolution of NATO Standards, MSG-165 MTDS-II, MSG-180 LVC-T) address the development of a common MTDS Reference Architecture (MTDS RA) for Joint and Combined Operations. The recently completed version of the MTDS RA defines guidelines in the form of building blocks, interoperability standards and patterns for realizing and performing synthetic collective training and exercises supported by distributed simulation, independent of application domain (land, air, maritime). In addition, MSG-164 (M&S as a Service II) developed a Technical Reference Architecture (MSaaS TRA) with building blocks for realizing a so called MSaaS Capability. These building blocks can be combined with the MTDS RA to include guidelines for performing synthetic collective training and exercises as a service.

The current version of the MTDS RA provides a baseline to elaborate on and to identify areas where further requirements/technology development should occur. Topics for future updates include cyber operations and effects, crisis management, live systems integration, and multi-domain or hybrid operations, to name a few.

Joint MTDS will be crucial to NATO and national readiness. This paper provides background, objectives and principles of the MTDS RA and the way ahead towards a persistent NATO wide synthetic collective training capability. The maintenance and continued development of the Joint MTDS RA will be a collaborative effort by several NATO nations, partner nations and organizations under the auspices of the NMSG.

1.0 INTRODUCTION

NATO and nations have a common need for combined and joint collective training to ensure mission readiness. There are, however, significant challenges: current and future operations are multinational in nature and require coordination between multiple actors to pursue common objectives; new systems and platforms are becoming more complex and require more preparation time to use. At the same time, opportunities for live training and mission preparation in a multi-national context are reduced due to fewer available resources and limited time span between political decision making and deployment. Cost, complexity, environmental restrictions, and improved hostile (electronic) monitoring capabilities often make it impossible to fully train with live systems in a real world environment.

Simulation has become an essential tool to meet the training demands of our military forces and nations are moving toward adopting national MTDS capabilities. Over time several NATO Modelling & Simulation Group (NMSG) initiatives (see [1]) have provided valuable inputs towards the development of a NATO MTDS vision and concept of operations, such as MSG-106 NATO Education and Training Network (NETN) and MSG-128 MTDS. So far, these have not led to a persistent NATO-wide capability to deliver meaningful synthetic collective training due to the lack of a common technical framework and the complexity of preparing a collective training event. The complexity is due both to technical aspects (e.g. number of different, often legacy, national simulation assets and interfaces) as well as organizational aspects (e.g., number of actors and disciplines). In addition, simulation assets may use different security domains where the exchange of data is subjected to national security policies. Depending on the scope and complexity of the exercise, the preparation of a synthetic collective training event can take several months up to sometimes a year when including initial planning meetings. Synthetic collective (and combined) training or mission rehearsals therefore only take place sporadically, while actual missions are increasingly being conducted in international coalitions and with short preparation time.

NATO MTDS should focus on areas not captured in existing training arrangements and deliver maximum value and efficiency in these areas. It therefore does not seek to replicate training delivered through existing national activities, but rather provide an additional coalition synthetic training capability. The NATO MTDS capability is intended to integrate national or NATO simulation assets into a distributed synthetic collective training environment where the assets are connected through a common simulation infrastructure. Building on previous results, ongoing NMSG activities (MSG-165 MTDS-II, MSG-169 LVC-T) aim to contribute towards developing an MTDS Reference Architecture (hereafter called "RA") for Joint and Combined Operations. The RA outlines requirements in the form of building blocks, interoperability standards and patterns for realizing and performing synthetic collective training and exercises supported by distributed simulation independent of application domain (land, air, maritime).

The RA addresses multiple stakeholder perspectives:

- For *nations and NATO* implementing synthetic collective training within their organizations, and for nations and NATO participating in NATO synthetic collective training events, the RA should be used to state standard capabilities, building blocks, patterns, and other attributes in order to assess conformance.
- For *product vendors*, the RA should provide a set of requirements and standards with enough specificity to enable vendors to develop products and evaluate compliance of their products with those requirements and standards.
- For *integrators*, the RA should be a reference source to define specific constraints and directions for implementing a synthetic collective training environment.
- For the *NMSG*, the RA should provide a reference against which technology and requirements can be developed, standards identified, guidelines provided, and more detailed levels of specificity defined.

This paper provides an overview of the RA and the architecture concepts used to delineate the different types of architecture.

2.0 ARCHITECTURE CONCEPTS AND FRAMEWORK FOR MTDS

Architectures can be designed at various levels of abstraction and one can distinguish between different types of architecture. There is little consensus in general on the various levels of abstraction or on how to name them. For instance, NATO Architecture Framework (NAF) [2] mentions different kinds of architecture and the activities leading to these architectures. The different kinds or types of architecture are shown in Figure 1.

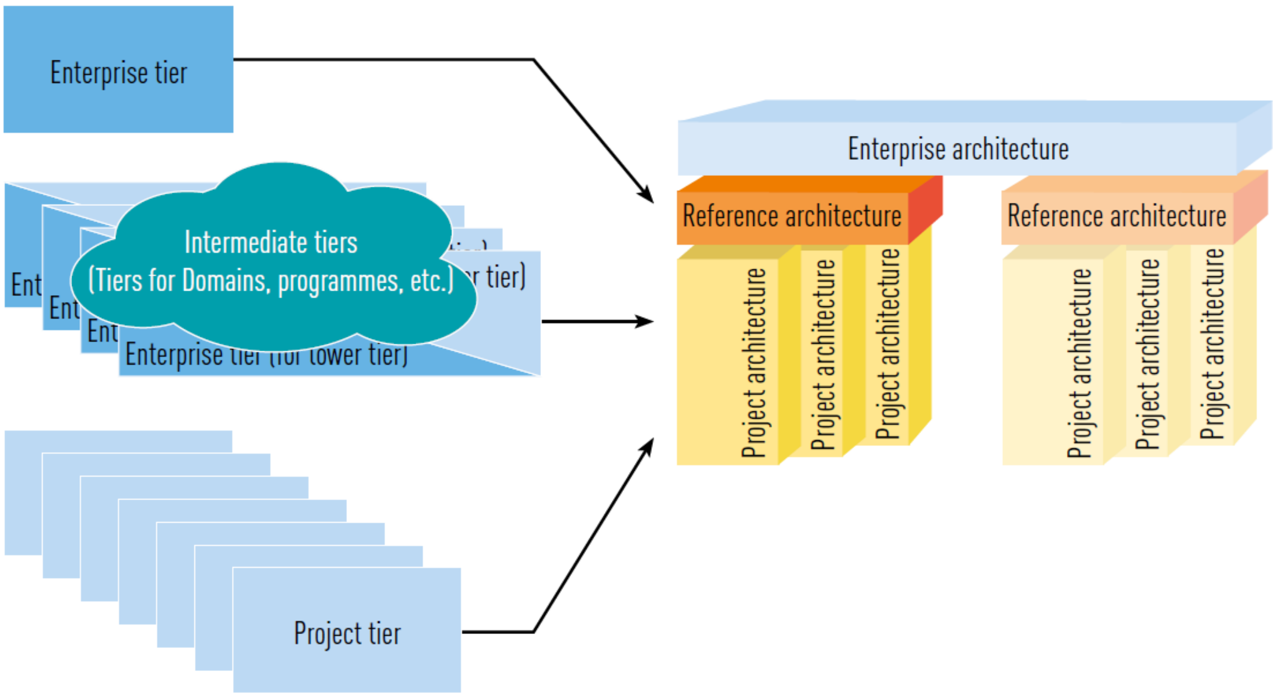

Figure 1: Kinds of architecture.

In this figure, enterprise architectures are developed by the enterprise tier activities, reference architectures are developed by domain and programme tier activities, and system architectures are developed at project tier activities. This document follows the same structure where domain and programme tier activities are performed by Task Groups under the umbrella of the NMSG, and project tier activities are performed by national or NATO projects.

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 is here referred to as an architecture framework [3]. The Architecture Framework for MTDS is shown in Figure 2.

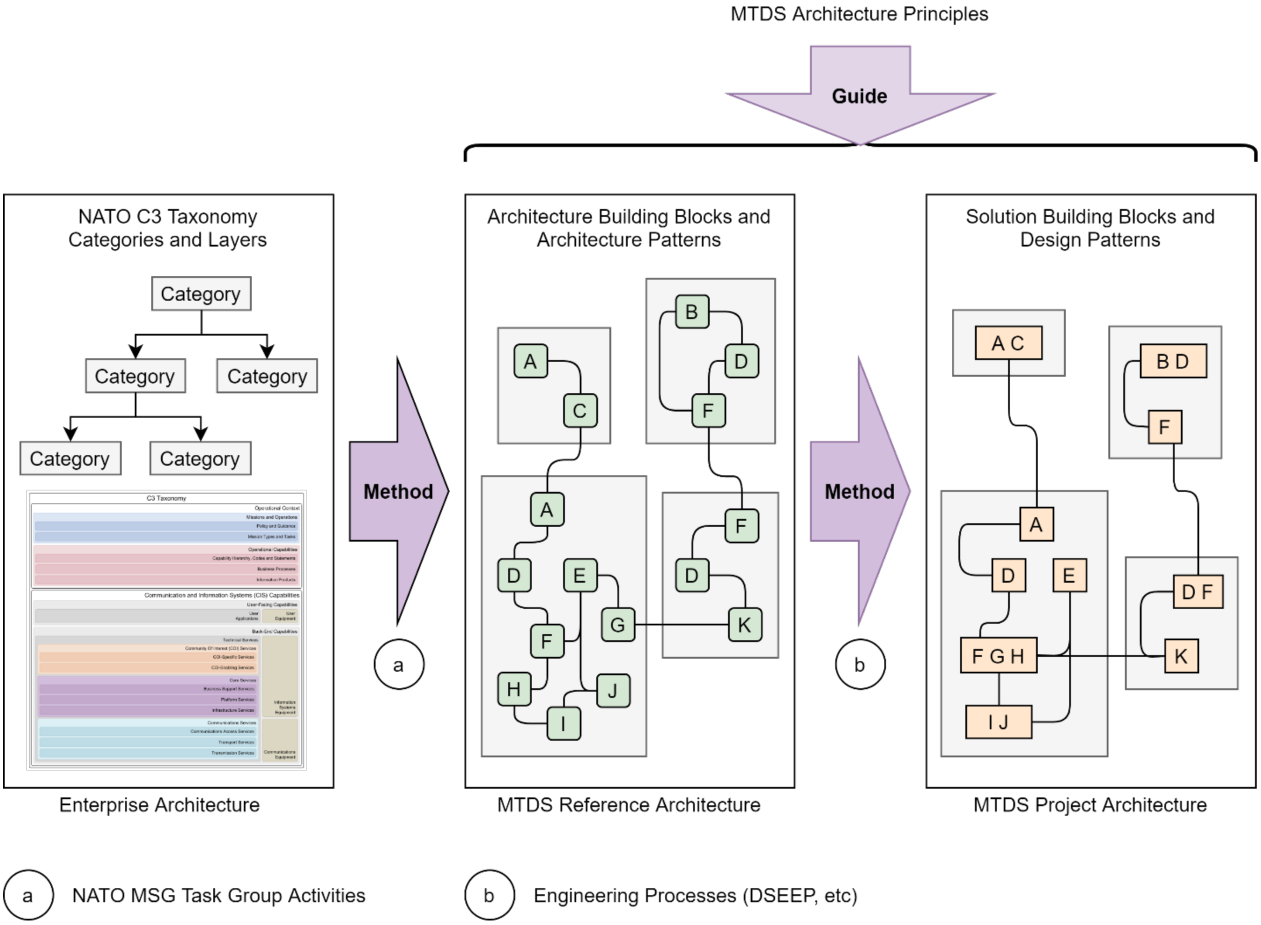

Figure 2: Architecture Framework for MTDS.

The methods in the figure refer to (a) Task Group activities and (b) Engineering Processes, such as the DSEEP [4]. Architecture development efforts are performed under guiding principles, briefly discussed later.

2.1 Enterprise Architecture

For the purpose of the MTDS RA, the NATO Consultation, Command and Control (C3) Taxonomy [5] is viewed as the *Enterprise Architecture*. In Figure 2 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 of concepts 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 C3 Taxonomy defines several categories of capabilities applicable to MTDS. For instance, Collective Training and Exercise (CTE) processes; Education, Training, Exercises and Evaluation (ETEE) Applications; and Technical Services, including M&S Services. These categories are a source of reference for the building blocks in the MTDS Reference Architecture. They provide both structure and requirements for the building blocks of the MTDS Reference Architecture.

2.2 MTDS Reference Architecture

This type of architecture is the focus of MTDS architecture development efforts. The *MTDS Reference Architecture* (RA) is developed and maintained under the umbrella of the NMSG through Task Groups and defines the building blocks and patterns that should be considered for the realisation of a synthetic collective training environment. In Figure 2 building blocks are illustrated by green boxes and patterns by grey boxes encompassing building blocks and relationships between them. Building blocks concern both process building blocks as well as technical building blocks. Process building blocks include, for example, the reference process for developing, planning and conducting a CTE event while technical building blocks include CTE and M&S applications to support this process as well as CTE and M&S services to connect training systems to the synthetic collective training environment.

2.3 MTDS Project Architecture

The architecture for a specific synthetic collective training event is called an *MTDS Project Architecture*. The project architecture is in Figure 2 illustrated by orange solution building blocks and the relationships between them. The letters refer to the building block in the reference architecture that is realized by the solution building block. A project architecture is, for example, the training environment architecture for the Spartan Warrior events organized by the US Air Forces in Europe (USAFE) Warrior Preparation Center [6] or the Viking events organised by the Swedish Armed Forces [7]. Since the RA provides the building blocks for a synthetic collective training environment, 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 RA. Still, refinement is generally needed to meet the requirements and constraints of the project (i.e. the training event). This could include the tailoring of the reference training processes as defined in the RA; the addition of security requirements; the selection of specific middleware solutions; the selection of gateway and bridge components, cross domain solutions, data recording solutions, and environmental data products and formats. Reference simulation data exchange models, such as defined in the NATO AMSP-04 [8], are provided through the RA, but the project architecture still requires agreements on which specific parts from these reference data exchange models are to be used.

So, from the same reference architecture, different project architectures may be developed, each specifying a particular implementation of a synthetic collective training environment that complies with the standards and requirements set in the reference architecture. The project architecture may concern a persistent training environment or an environment that only exists temporarily for the purpose of a particular training event.

2.4 Architecture Principles

Architecture Principles govern the process of developing, maintaining, and using the MTDS Reference and MTDS Project Architectures. Principles are persistent general rules and guidelines informing and supporting how NATO and partner nations can fulfil a mission. In Figure 2 this is illustrated with the “Guide” arrow.

The attributes of Architectural Principles are defined using The Open Group Architecture Framework (TOGAF) [9], and include:

Name Represent the essence of the rule.

Statement Should succinctly and unambiguously communicate the fundamental rule.

Rationale Should highlight the business benefits of adhering to the principle.

Implications Should highlight the requirements, both for the business and IT, for carrying out the principle - in terms of resources, costs, and activities/tasks.

Ten main Architecture Principles for the RA were developed by MSG-165 (see MSG-165 RA Technical Report [10]). Following is one of the principles:

1. **Name**: Comply with NATO policies and standards

2. **Statement**: MTDS shall be compliant with NATO policies and agreements with respect to M&S interoperability and standards.

3. **Rationale**: The aim of these policies and agreements is to facilitate system-level interoperability within and between all Level 3 (Command and Staff), Level 2 (Tactical), and Level 1 (Individual and Crew) modelling and simulation (M&S) systems. The scope of these policies and agreements includes M&S systems that are used for operations, training and analysis. This applies to M&S systems developed by, and located in, different NATO nations and NATO organizations.

4. **Implications**: The following baseline policies and agreements shall apply to MTDS: AMSP-01: M&S Standards Profile, STANREC 4815 [11]. STANAG 4603: Modelling and Simulation Architecture Standards for Technical Interoperability: High Level Architecture (HLA) [12]. AMSP-04: NETN Federation Architecture and FOM Design, STANREC 4800 [8]. AMSP-03: Guidance for M&S Standards in NATO and Multinational Computer Assisted Exercises with Distributed Simulation, STANREC 4799 [13].

In MTDS context the Architecture Principles are used to capture information about how NATO nations and NATO organisations should use and deploy M&S resources and assets for synthetic collective training. Amongst others, the principles drive the definition of functional requirements in Architecture Building Blocks, guide the evaluation of project architectures, and provide motivations through the rationales.

2.5 Architecture Building Block and Architecture Pattern

The notions *Architecture Building Block* (ABB) and *Architecture Pattern* (AP) are used to describe the building blocks in the RA and how these building blocks may be combined. These notions are illustrated in Figure 3 and Figure 4, where the first figure also shows as comparison the notion *Solution Building Block* (SBB).

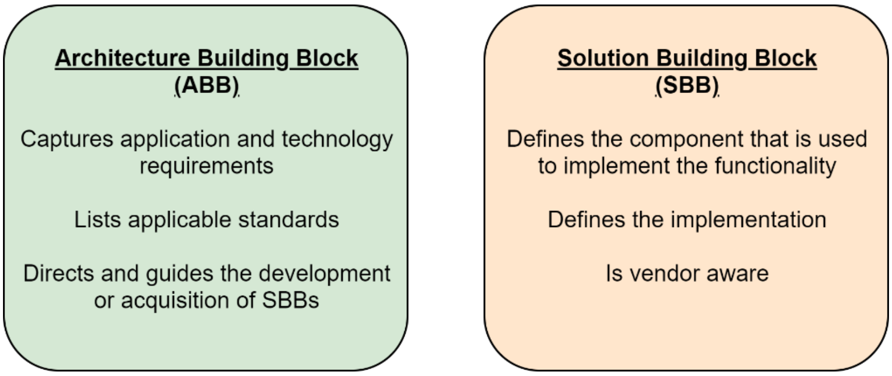

Figure 3: Architecture Building Block vs Solution Building Block.

An ABB has attributes that specify its purpose, function and required technical interfaces, as well as any applicable standards. An ABB is not meant to be a specification of a specific solution but provides requirements, standards and guidance for developing the architecture of a synthetic collective training environment, i.e. a project architecture. A SBB on the other hand relates to a specific solution (and hence project architecture) that may be procured or developed. A SBB specifies amongst others the required functionality, specific interfaces, actual performance values, and construction constraints for the training event. The notions ABB and SBB are derived from TOGAF [9].

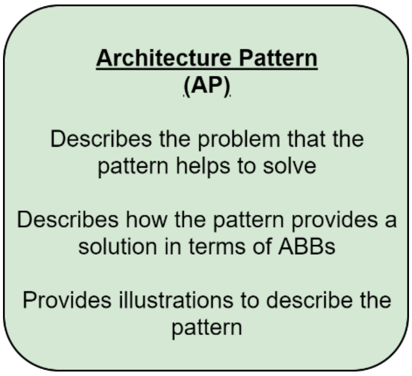

Figure 4: Architecture Pattern.

An AP serves as reference for a project architecture, providing information on combinations of ABBs that have proven to provide a solution for a certain problem. Pattern attributes include a description of the problem that the pattern helps to solve, a description of how the pattern provides a solution to the problem, and illustrations to help describe the pattern. Other pattern attributes specify functional and non-functional requirements, list applicable standards, and provide references and examples.

The RA description uses AP illustrations as in Figure 5. This simplified illustration shows two interacting ABBs, exchanging data objects with associated interface requirements and standards. Examples are provided in chapter 3.0.

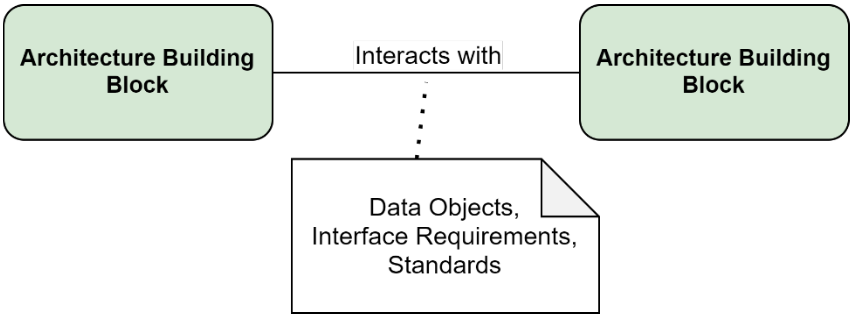

Figure 5: Illustration of an Architecture Pattern.

3.0 RA LAYERS AND BUILDING BLOCKS

Figure 6 provides an overview of the layers in the RA, organized in line with the main layers of the NATO C3 Taxonomy:

- Operational Capabilities: capabilities for collective training and exercises in terms of processes, information products, roles and organisation. In the C3 Taxonomy the related categories are located under *Operational Capabilities > Business Processes > Enable > ETEE > CTE*.
- User-Facing Capabilities: capabilities to support the CTE Processes as well as capabilities to be used by the Training Audience. In the C3 Taxonomy the related CTE categories are located under *User-Facing Capabilities > User Applications > ETEE Applications > CTE Applications*. And related

M&S categories under *User-Facing Capabilities > User Applications > M&S Applications*.

- Back-End Capabilities: capabilities to enable or support the User-Facing Capabilities. Relevant categories in the C3 Taxonomy are under *Back-End Capabilities > Technical Services > COI Services > COI-Specific Services > ETEE Functional Services*, and under *Back-End Capabilities > Technical Services > COI Services > COI-Enabling Services > M&S Services.* Also the Core and Communication Services include several categories relevant to managing and securing the technical components in a synthetic collective training environment.
- Service Management and Control (SMC), and CIS Security are depicted as two cross cutting layers in the RA. In the latest versions of the C3 Taxonomy these cross-cutting layers have been removed from the overview, however the underlying categories are present in every layer of the taxonomy. For the purpose of the RA we keep these layers in the overview to emphasize the cross-cutting concerns of SMC and security in collective training and exercises.

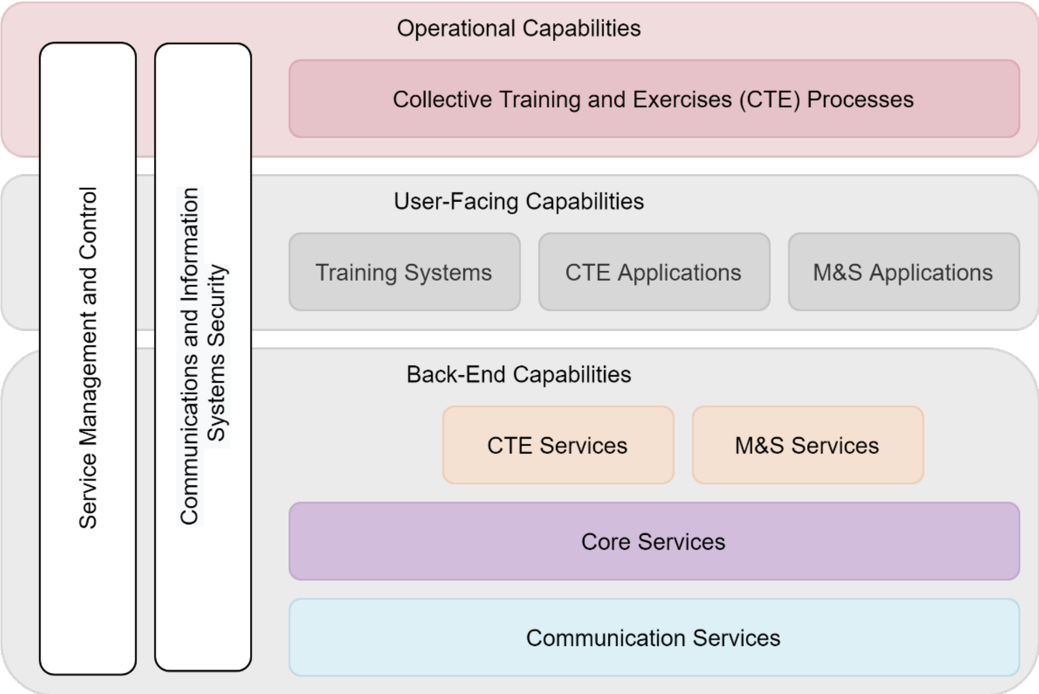

Figure 6: Layers and clustering of main MTDS Architecture Building Blocks.

The following sections describe each of the layers of the RA and the final section introduces the MTDS Technical Framework. More detail is included in the MSG-165 RA Technical Report [10].

3.1 Operational Capabilities

This layer defines the *Collective Training and Exercises (CTE) Processes*. These define the general process steps that should be followed in performing a synthetic collective training, as well as the information products that should be developed along this process. The CTE Processes are described in NATO Bi-SC 75-3 Collective Training and Exercise Directive [14], providing the reference process as well as a comprehensive guideline on planning, executing, and assessing NATO collective training and military exercises

The CTE Processes also include the development or adaptation of the synthetic collective training environment itself. AMSP-05 NATO Handbook for Computer Assisted Exercises (CAX) [15] provides additional M&S related guidelines, complementing Bi-SC 75-3 Annex N (Synthetic Environment Support to Exercises). This handbook includes a more specialized process description for simulation-based training events.

Engineering processes to design, develop, implement and test the technical components of a training environment are also included in this layer. This includes the Distributed Simulation Engineering and Execution Process (DSEEP), the Reuse and Interoperation of Environmental Data and Processes (RIEDP), and V&V activities:

- The DSEEP [4] is a process model that defines seven steps to design, develop, integrate, test a simulation environment and execute a simulation. The DSEEP allows users to tailor the process model to their specific application requirements, i.e. a synthetic collective training environment.
- The RIEDP [16] defines the components needed for the sharing of environmental data products. It includes a reference process model, an abstract data model, and a metadata specification to support repository and catalogue requirements. The development of environmental data products as part of the project architecture development activities is critical. Therefore, it is crucial to integrate the RIEDP activities with the DSEEP steps and activities in the engineering of the synthetic collective training environment.
- If a validation and/or verification is required for the synthetic collective training environment, then the VV&A overlay to the FEDEP [17], or the Guide for Generic Methodology for Verification and Validation (GM-VV) [18] should be considered.

All these reference processes typically need to be tailored to meet national or multi-national training requirements and project-specific constraints. Factors that influence tailoring include variations in the training environment; risks; maturity, size and complexity of solutions; the timing of the training event; technology readiness (emerging or legacy); budget; availability of systems and personnel; requirements on verification and validation; and security-related requirements.

3.2 User-Facing Capabilities

This layer contains the Training Systems as well as the M&S and CTE Applications used to support synthetic collective training. These are applications that users interact with, hence “User-Facing”.

M&S and CTE Applications include (and is not limited to): *Scenario Development Applications* (for the development of conceptual and executable scenarios), *Synthetic Physical Environment Applications* (for the development of environmental data products), and *Exercise Control Applications* (for the control of the scenario execution).

Training Systems are national assets, but are included in this cluster since, from the RA point of view, these are considered as User-Facing Capabilities. Training Systems range from relatively simple single-element systems, such as dedicated CGF applications, to more complex multi-element systems, such as full mission simulators. It is not in the scope of the RA to discuss Training Systems themselves, but rather how the capabilities are federated in a synthetic collective training environment.

Training Systems interact with several of the services in the other layers, for example:

- Back-End Capabilities:
    - M&S Message Oriented Middleware (MOM) Services coordinate the exchange of simulation data between Training Systems and M&S/CTE Services.
    - Simulation Portal Services perform simulation data protocol conversions, enabling

incompatible or partially compatible Training Systems to connect with the M&S MOM Services.

- Scenario Distribution Services provide scenario initialization data to Training Systems, enabling a coherent scenario initialization of Training Systems.

- CIS Security:
  - CDS Services provide the means to control the release of simulation data from one security domain to another.
  - M&S MOM Services enable the secure exchange of simulation data between sites.
- Service Management and Control:
  - SMC Services enable an orderly start and stop of Training Systems and provide the ability to meter and monitor Training Systems.

3.3 Back-End Capabilities

This layer encompasses several building blocks. M&S and CTE Services in this layer define MTDS specific capabilities. Training Systems and Applications interact with these Back-End Capabilities, such as Simulation Portal Services to connect Training Systems to the M&S Message Oriented Middleware Services.

The Core Services in this layer define a number of general capabilities that need to be in place for any synthetic collective training environment. Similarly, Communication Services are general communication capabilities that are essential for any synthetic collective training environment. These are included here for reference and are not discussed in any great depth.

M&S and CTE Services in this layer include amongst others:

- *Simulation Portal Services*. In many synthetic collective training environments there will be a mix of Training Systems, each supporting different (versions of) simulation standards, tactical data links, and/or HLA FOM modules, e.g. DIS version 7, IEEE 1516.2000 (HLA), IEEE 1516.2010 (HLA Evolved), RPR-FOM, NETN-FOM modules, or different Tactical Data Link simulation standards. The RA defines Simulation Portal Services to perform the most commonly found transformations required to connect Training Systems using non-HLA (e.g. DIS) or legacy HLA (e.g. HLA 1.3) to the M&S Message Oriented Middleware Services
- *M&S Message Oriented Middleware (MOM) Services*. These Services enable the interoperability of M&S and CTE Applications and Services, as well as Training Systems. The Message Oriented Middleware Services comply with NATO STANAG 4603 and NATO Standard AMSP-04. NATO STANAG 4603 mandates the use of the IEEE 1516™-2010 (HLA Evolved) standard on High Level Architecture for distributed simulation environments. AMSP-04 (NETN) defines a set of (coherent) HLA FOM modules, along with architecture and design guidelines, see Figure 7. The NETN FOM modules are designed to maximize re-use and interoperability between simulation components.

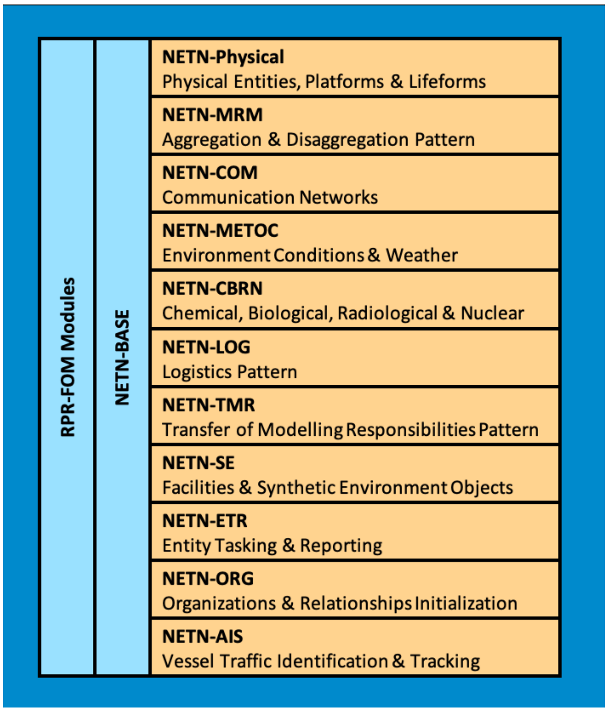

Figure 7: NETN FOM modules in AMSP-04 Edition B.

- *Scenario Distribution Services*. These Services provide the initial simulation scenario (such as Order of Battle (ORBAT) data) for the simulation execution, as developed by the Scenario Development Applications. The initial simulation scenario includes information about units, equipment items, and their relationships, as well as information about the initial modelling responsibility. I.e. what Training Systems are responsible for the modelling and simulation of what units and equipment items.
- *Simulation Services*. These Services generate both ground truth and non-ground truth data to stimulate Training Systems with (simulated) air, land or maritime platform or aggregated information, such as enemy aircraft, missiles, decoys, land units, air traffic, and maritime vessel traffic. The Simulation Services are controlled by Exercise Control Applications.

The RA also includes Architecture Patterns, providing information on how Architecture Building Blocks may be combined. Two patterns are illustrated below.

Figure 8 illustrates an Exercise Control pattern, where simulation entities are tasked from Exercise Control Applications. The M&S MOM Services route tasks between the Simulation Services and Training Systems, and it is transparent to the Exercise Control Applications where simulation entities reside and thus which component has modelling responsibility. The AMSP-04 NETN-ETR is a standard for the tasking and reporting of simulation entities in the warfare domain.

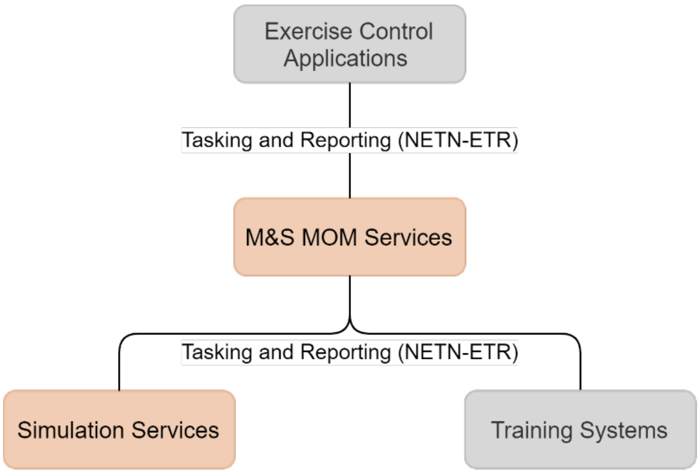

Figure 8: Pattern for tasking and reporting of simulation entities.

Figure 9 provides a patterns for scenario initialisation, where the initial simulation scenario is provided to the Scenario Distribution Services from the Exercise Control Applications. The scenario is distributed to Training Systems at run-time by the Scenario Distribution Services using the M&S MOM Services. The modelling responsibility of scenario elements is transparent to the Scenario Distribution Services. Training Systems are required to take responsibility for the modelling of the assigned elements as agreed in the simulation environment agreements. This pattern uses AMSP-04 NETN-ORG as the standard for scenario initialisation. The Scenario Distribution Services support HTTP for posting amongst others MSDL data.

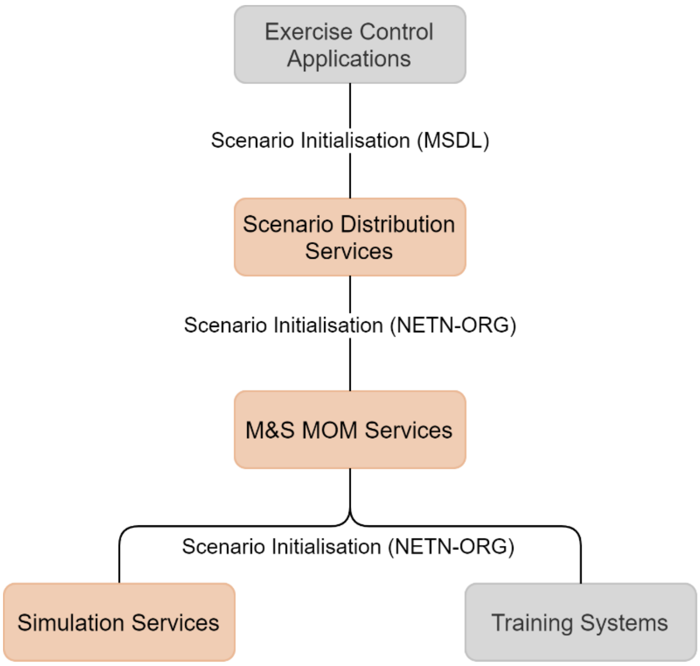

Figure 9: Pattern for scenario initialization.

3.4 Communications and Information Systems (CIS) Security

This layer is a cross-cutting layer and defines building blocks and patterns related to the exchange of data between different security domains in a synthetic collective training environment, the assessment of information security vulnerability, and the assessment of the impact of release policies on training objectives. Accreditation processes are also part of this cross-cutting layer. In addition, building blocks in the other layers may also include CIS Security requirements. For instance, for the M&S MOM Services to support mechanisms to securely exchange data between sites in a federated synthetic collective training environment.

Building blocks in this layer provide functionality for security-enforcement, management and monitoring. These building blocks provide guidelines and considerations in terms of requirements for implementing a M&S CDS solution, and facilitate the selection of adequate technology for SBBs. Building blocks include:

- *Security Policy Configuration Management Applications*: to provide the means to configure the other building blocks in this set;
- *M&S Guard Services*: to provide the ability to connect the national simulation security domain to the NATO MTDS security domain and control the release of simulation data from the national domain according to a set of predefined release policy rules;
- *M&S Mediation Services*: to provide the means to mediate the exchange of simulation data between Training Systems or M&S MOM Services, and M&S Guard Services.

A simplified pattern for cross-domain information exchange is provided in Figure 10. M&S Mediation Services transform data in a format that can be interpreted by the M&S Guard Services. The interface between M&S Mediation Services and M&S Guard Services is solution specific, but typically concerns XML or plain-text formatted messages for the M&S Guard Services to inspect and filter on. Implementations of M&S Guard Services are mostly national (classified) and proprietary solutions, and considered to be M&S specific due to M&S requirements related to latency and throughput of simulation data for example. Training Systems are located at national sites, in this example Site X and Site Y, where Communications Services (e.g. CFBL-Net) provide IP uni/multicast networking services across the sites. In addition, cryptographic equipment (if used, not shown in figure) ensures encrypted data communication between sites.

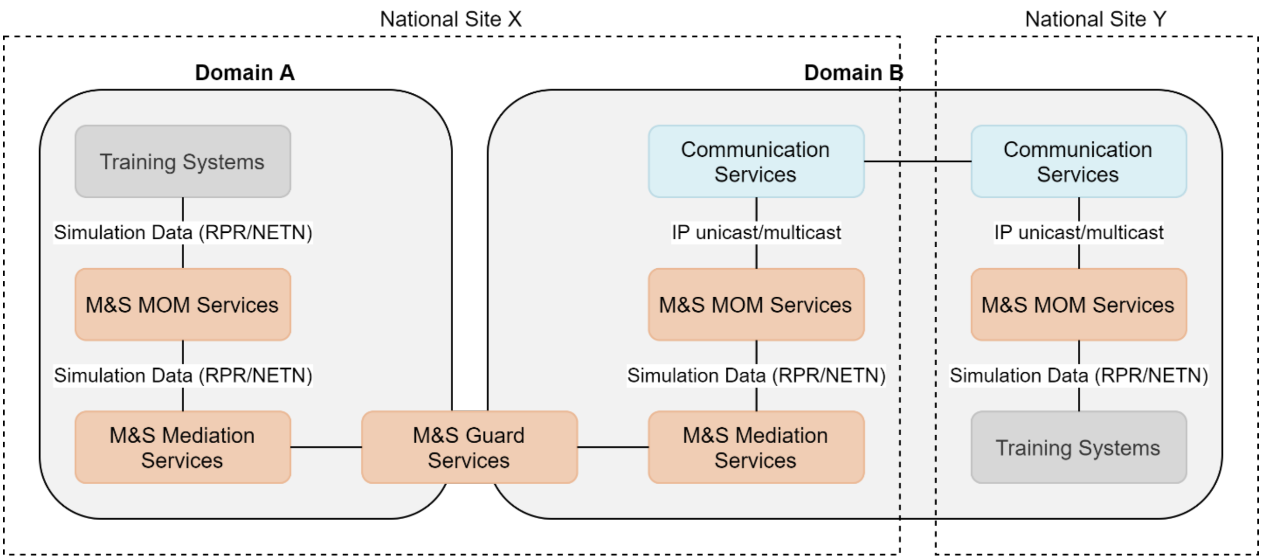

Figure 10: Pattern for cross-domain information exchange.

3.5 Service Management and Control

The Service Management and Control (SMC) cluster is also a cross-cutting layer as it affects all other layers.

This layer defines a collection of building blocks to coherently manage components in a (federated) synthetic collective training environment. This concerns processes as well as technical capabilities.

SMC capabilities provide the means to:

- Test Training Systems and test Applications and Services in the MTDS Technical Framework (see next section);
- Initialize and start the Applications and Services in the MTDS Technical Framework;
- Supervise the Applications and Services in the MTDS Technical Framework w.r.t. health and operating status;
- Monitor the status of Training Systems;
- Terminate the Applications and Services in the MTDS Technical Framework,

Applications and Services in this cluster include:

- *System Initialization and Termination Services*: to coherently initialize and terminate the Training Systems, and the Applications and Services in the MTDS Technical framework. These Services orchestrate the initialization and termination of components. Once a component has successfully started further coordination w.r.t. initialization and synchronization with other components, for example, is up to the component itself.
- *Monitoring, Metering, and Logging Applications and Services*: to collect and provide information about the health and performance of the Applications and Services in the MTDS Technical Framework. For example, monitor the liveness of components, collect metrics from components (e.g. CPU usage, numbers of messages exchanged), and collect log data from components (e.g. console logs). These Services are basic enablers in any distributed simulation environment.

  Figure 11 illustrates a pattern where Platform Monitoring Services monitor the liveness and readiness of M&S Services. Readiness indicates a state where the service is ready to participate in the simulation execution. Liveness indicates a state where the service is executing as planned. Platform Monitoring Services can issue liveness requests to M&S Services to determine their status, for example via HTTP GET probes. Platform Monitoring Services are non-M&S specific services, defined in the Core Services layer of the RA.

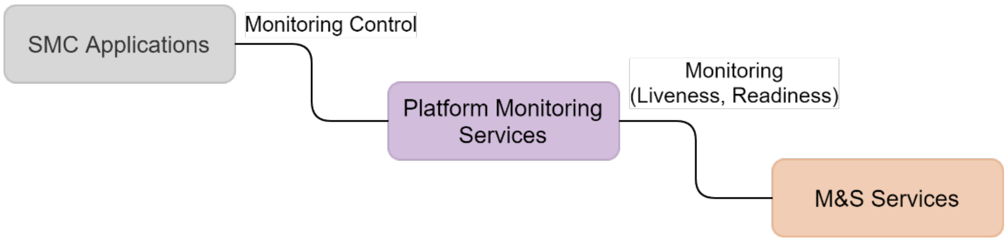

Figure 11: Pattern for monitoring of M&S Services.

- *Test Management Applications*: to verify that solutions for CTE/M&S Applications and Services, and Training Systems function properly; that is, comply with the agreed simulation interoperability requirements. The NATO IVCT [19] is a solution that can be used to test the interoperability capabilities of HLA simulation components and to support the integration of federated simulations.

3.6 MTDS Technical Framework

The communication and information systems capabilities that need to be in place to support a synthetic collective training and exercises constitute what is called the "MTDS Technical Framework". This Technical Framework is illustrated in Figure 12. It consists of the technical building blocks discussed in the previous sections (less the Training Systems), grouped together in a coherent set of technical capabilities.

In summary, the MTDS Technical Framework supports the activities in the CTE processes, provides the ability to securely and coherently exchange information between Training Systems at different sites, provides the ability to collect, store and process training and exercise related data, and provides the ability to stimulate Training Systems with information generated by M&S Applications or M&S Services. The building blocks and patterns in the Technical Framework together provide the technical requirements for integrating Training Systems in a (federated) synthetic collective training environment.

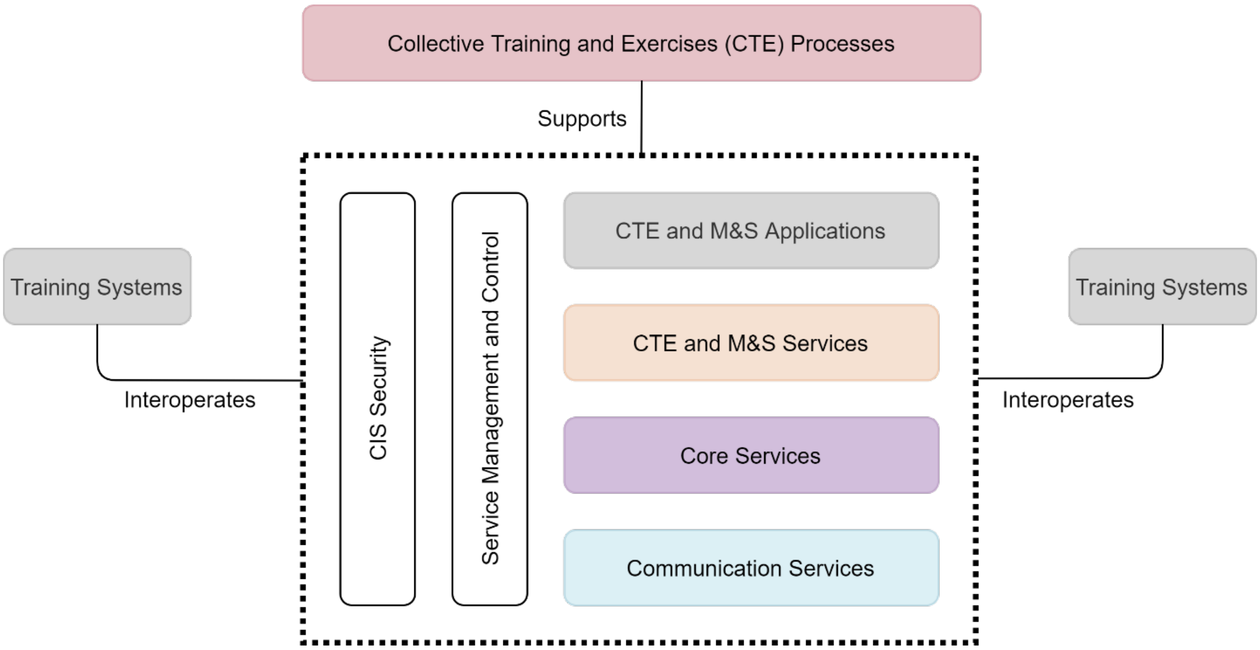

Figure 12: Pattern for MTDS Technical Framework.

4.0 SUMMARY AND CONCLUSIONS

This paper provided an overview of the MTDS Reference Architecture (RA). The RA provides a source of reference and direction regarding the design, development and implementation of a synthetic collective training environment for MTDS. The RA is described in terms of Architecture Building Blocks (ABBs) and Architecture Patterns (APs) grouped in layers. Each ABB provides requirements and standards, and each AP provides information on how ABBs may be combined. The building blocks and patterns provide directions for the development or acquisition of solutions to ABBs and APs. In addition, the RA defines Architecture Principles to guide the development, maintenance and use of the RA.

The RA has a strong link with the NATO C3 Taxonomy, providing traceability to NATO's Consultation, Command and Control (C3) capabilities, as well as a common structure to name and organize building blocks in a way that is recognizable across the NATO C3 community of users.

The RA provides (1) a *framework and structure* of which (2) the *content* (that is, ABB and AP descriptions) can continuously be improved and enriched as demand and insights evolve over time. The present RA version developed by MSG-165 already provides a baseline with several ABBs and APs. However, a number of gaps are identified for which ABBs and APs should be developed and added to the RA description (see MSG-165 RA Technical Report, [10]). There are also opportunities to leverage ongoing scientific and technical work that should be integrated and aligned with the RA.

5.0 RECOMMENDATIONS

To nations and NATO:

- Use the RA as the reference for implementing synthetic collective training within the organization and participate in NATO synthetic collective training events to gain practical experience, develop technical capability and provide operational training value.

To the NMSG:

- Use the RA as the reference for synthetic collective training against which technology and requirements can be developed, standards identified, guidelines provided, and more detailed levels of specificity defined.
- Ensure that the RA is maintained and kept up to date by successive Task Groups.
- Organise the MTDS-related topics (see MSG-165 RA Technical Report, [10]) in a roadmap, to be used for incremental development of the *content* of the RA.
- Adopt the RA and promote its use by nations when implementing MTDS.
- Evaluate the integration of the RA in AMSP-03 [13], updating and evolving this profile toward a profile for Joint-MTDS.

To integrators and product vendors:

- Align products with the requirements and standards listed in the RA.

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