Advancing Modelling and Simulation in NATO Federated Mission Networking

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ABSTRACT

Federated Mission Networking (FMN) is a major NATO thrust to support interoperability, focusing on "Day Zero" interoperability in use/application of multi-national systems in coalition operations. Participants recognize the benefits of modelling and simulation (M&S) in supporting military operations, from training to rehearsal to decision support. The NATO Modelling and Simulation Group (NMSG) has supported the specification process for M&S-enabled capabilities in the FMN under previous MSG-193 and current MSG-201 activities over the past four years. Standards and best practices identified for integrating M&S into FMN include: (1) High Level Architecture (HLA), standardized under the Institute of Electrical and Electronic Engineers (IEEE) and approved under NATO Standardization Agreement (STANAG) 4603 Ed 03; (2) NATO Education and Training Network Federation Object Model (NETN-FOM); (3) Command and Control Systems - Simulation Systems Interoperation (C2SIM) (approved under STANAG 4856 Ed 01); (4) Modelling and Simulation as a Service (MSaaS). Developers and operators are employing these products in the current Coalition Warrior Interoperability Exercise (CWIX) testing the use of M&S in FMN. This paper presents an overview of each of the identified M&S standards applied to FMN development and considers their use in FMN implementation of Multi-Domain Operations (MDO).

1.0 INTRODUCTION

NATO operational commands have undertaken a major initiative to specify Federated Mission Networking (FMN), defining how NATO and coalition partners' information systems will interoperate in the future, with emphasis on coalition-wide command, control, and consultation capabilities. This paper describes work in MSG-201 *Modelling and Simulation in FMN* supporting the specification of M&S aspects of FMN.

1.1 What is FMN and why is it important

The aim of FMN is to provide standards and practices for secure, scalable, flexible and agile federated Mission Networks (MN) [1]. The goal is that accredited applications can safely and reliably exchange data and information supporting coalition operations. Following long experience with NATO's International Security Assistance Force (ISAF) operations and similar coalition activities, it was concluded that a new networking approach was needed to enable Day Zero, mission-ready networking capabilities for future deployments and to support evolving command and control requirements. The initiative is led by NATO's Allied Command Transformation (ACT) co-operating with NATO's Allied Command Operations (ACO). Clearly, FMN needs M&S; equally clearly, M&S will gain most effective use only if it is deployed as part of FMN [2]. Supporting details can be found in [3].

1.2 FMN Spiral Implementation

Development of FMN specifications is structured as an overlapped sequence of "spirals," as shown in figure 1. Each spiral specification stage has four milestones: Draft, Candidate, Proposed and Final. Spirals 1 through 4 have reached the Final specification milestone. MSG-201 participated in Spiral 5 as a "syndicate" to support the specification of M&S for Mission Rehearsal. Ultimately Spiral 5 was restricted to make implementation by the nations more achievable and our Mission Rehearsal work has been incorporated in Spiral 6. Our activity intends expanding in 2025 based on a proposal to include additional M&S support in Spiral 6: M&S for Collective Training.

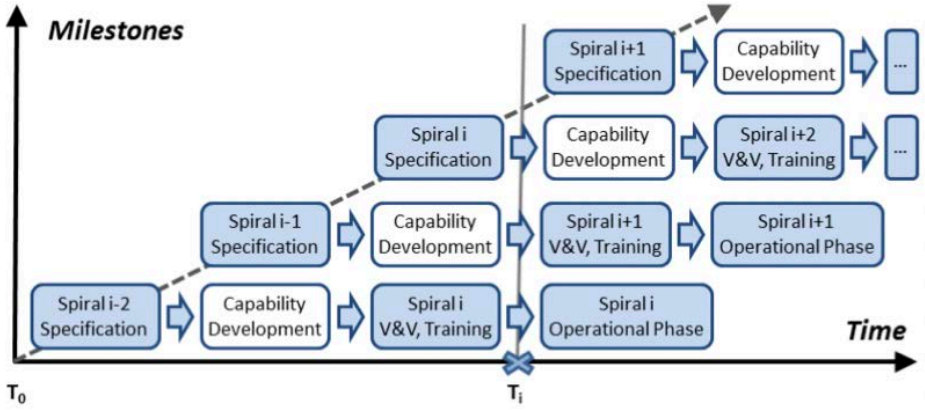


Figure 1: The FMN Spiral Development Process [4]

The operational requirements for FMN capabilities are specified in documents called Procedural Instructions (PI), describing what information is needed when, and by whom, in order to achieve a particular FMN function. The technical specifications supporting the actual implementation are part of documents called Service Instructions (SI). The PI includes architectural elements based on the NATO Architecture Framework v4 using ArchiMate Viewpoints and related diagrams. Each diagram is accompanied with a narrative that explains each activity, role, and information exchanges.

1.3 CWIX supports FMN development

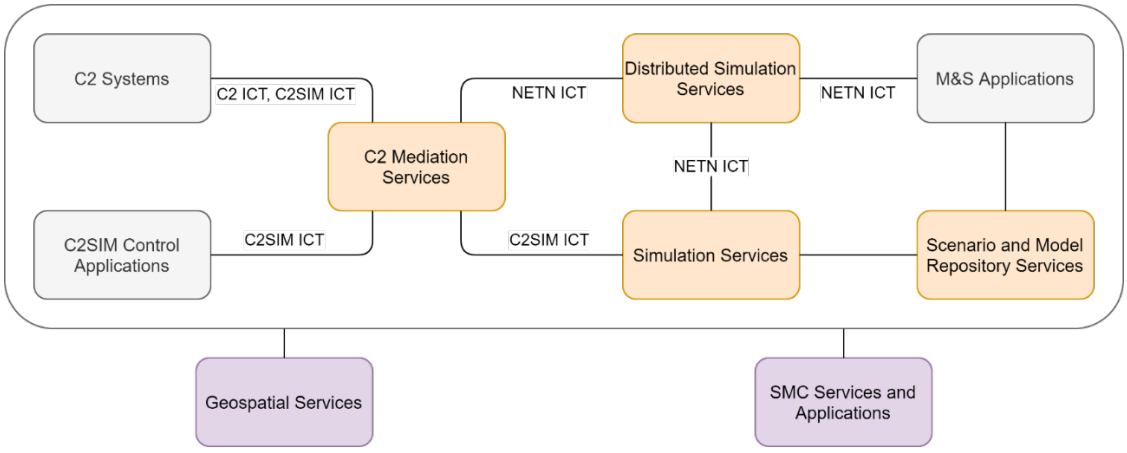
The effectiveness of FMN depends on the national affiliates collaborating to reach and test implementable specifications based on existing NATO and commercial standards. The annual *Coalition Warrior Interoperability Exploration, Experimentation, Examination and Exercise (CWIX)* involves all stages of

ongoing specification and implementations, tested either in person or via secure network or semi-secure Internet VPN. CWIX provides a structured testing methodology, coupled with a testing environment that enables evaluation of system interoperability and visibility of results, providing an excellent environment for evaluation and demonstration of the appropriateness of standards and practices for FMN [5].

2.0 M&S STANDARDS PROPOSED FOR FMN

To begin integration of M&S capabilities into FMN, MSG-194 and MSG-201 identified a number of standards and best practices that would provide an initial foundation for development; namely, (1) High Level Architecture (HLA) [6]; (2) NATO Education and Training Network Federation Object Model (NETN FOM) [7]; (3) the C2 Systems – Simulation Systems Interoperation (C2SIM) standard [8]; and (4) Modelling and Simulation as a Service (MSaaS) [9]. The following subsections provide a brief description of each of these components.

To place the selected standards and best practices in an architectural context, figure 2 identifies key aspects of the M&S architecture proposed for FMN [10]. The architecture enables the exchange of initialization, control, tasking, and reporting (ICT) information among C2 systems and M&S applications through C2 Mediation Services, Distributed Simulation Services, Simulation Services, and Scenario and Model Repository Services. The C2SIM Control Applications coordinate cross-system initialization and control of cross-system message interchange (e.g., such functions as pause/resume, record/playback, among others) in conformance with the C2SIM standard. Distributed Simulation Services manage execution and information exchange across the distributed simulation systems operating under the HLA standard in accordance with specification of objects and interactions in the NETN FOM. Simulation Services coordinate the information translation between C2SIM messages and NETN FOM messages used in the HLA framework. The Scenario and Model Repository Services employ MSaaS mechanisms to store and access scenario information used by the simulation systems.



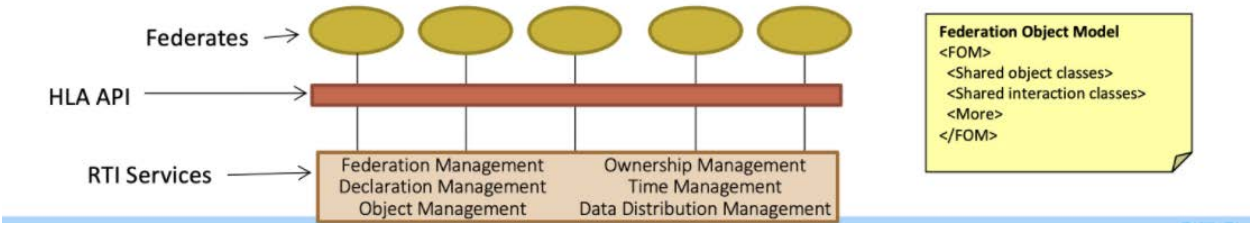
C2: Command and Control; C2IS: C2 Information System; C2SIM: C2 Systems – Simulation Systems Interoperation; ICT: Initialization, Control, Tasking and Reporting interactions; M&S: Modelling and Simulation; NETN: NATO Education and Training Network

Figure 2. M&S Architecture in FMN [10]

2.1 High Level Architecture

The High Level Architecture (HLA) for M&S is an international standard developed by the Simulation Interoperability Standards Organization (SISO) under the authority of the Institute of Electronic and Electrical

Engineers (IEEE) [6]. NATO has adopted HLA as Standardization Agreement 4603 [11]. The HLA standard specifies a set of rules and a software framework for managing the exchange of information across distributed simulation systems and coordinating the execution of the distributed simulation systems. Figure 3 illustrates the HLA concept where individual simulations or other software applications ("federates") interchange information and send/receive control information though a specified application program interface (API). Users of the HLA standard specify a simulation data exchange model in accordance with a standardized Federation Object Model (FOM) format identifying objects and interactions for the specific federation.



API: Application Program Interface; FOM: Federation Object Model; RTI: Run-Time Infrastructure

Figure 3. HLA Concept [12]

2.2 NATO Education and Training Network Federation Object Model

The NATO Education and Training Network Federation Object Model (NETN-FOM) [7] defines the objects and interactions needed for information interchange across HLA-conformant distributed simulation systems operating in the FMN environment. The NETN-FOM is composed of several modules (see figure 4) representing different classes of information, most prominently the NETN-ORG describing military organizations defined in the scenario and NETN-ETR (Entity Tasking and Reporting) defining orders and reports to be exchanged across the federates.

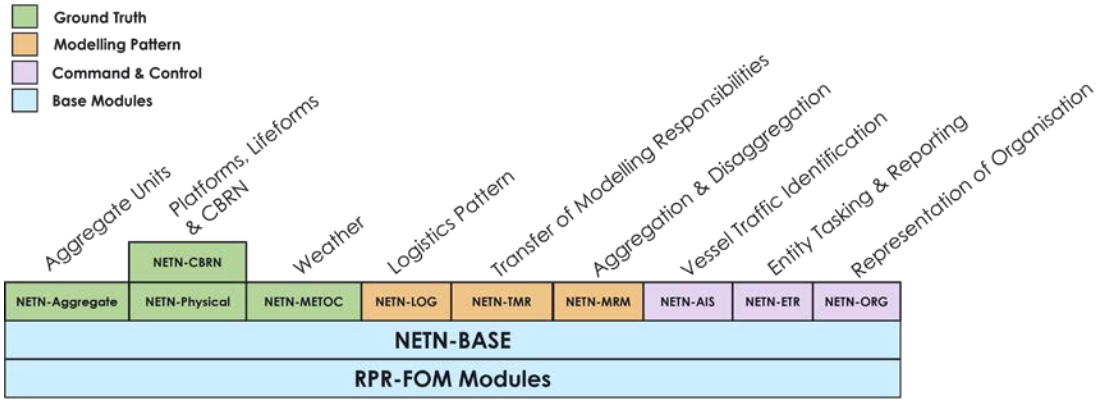


Figure 4. NETN-FOM Principal Components [7]

2.3 Command and Control Systems – Simulation Systems Interoperation

The Command and Control Systems – Simulation Systems Interoperation (C2SIM) is an international standard produced by SISO for specifying information interchange across C2 systems, simulation systems, and robotic and autonomous systems (RAS) [8]. Figure 5 illustrates the C2SIM concept for information interchange across different classes of systems.

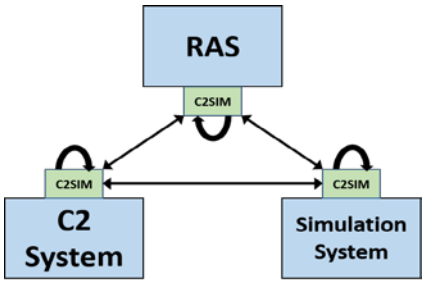


Figure 5: C2SIM Concept [13]

Data exchanged under C2SIM is specified as an ontology using the Web Ontology Language [14]. Use of an ontology permits expression of stronger semantics, offering benefits in automated reasoning, strong validation, query, and information-linking [15]. Other domain models can be included by developing extensions to the core C2SIM data model, as shown in the Land Operations Extension to C2SIM [16] and proposed for the cyberwarfare domain [17]. The C2SIM products from SISO include a guide providing information to help new users develop applications that are conformant to the C2SIM standard [18]. There are initial efforts to create explicit integration of NETN-FOM information with the C2SIM data model [19]. Furthermore, NATO has adopted C2SIM as Standardization Agreement 4856, Edition 0 [20].

2.4 Modelling and Simulation as-a-Service

Modelling and Simulation as-a-Service (MSaaS) is an architecture for exploiting extensible computing and storage resources "in the cloud," combining "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" [9]. M&S applications, data, and support tools are made available through well-defined services that can be accessed by anyone and any system operating in the FMN environment. Figure 6 identifies primary components of the MSaaS concept and the connections to systems supporting the warfighers. The cloud-based architecture is designed to adapt automatically to instantaneous changes in overall system demand for computing resources.

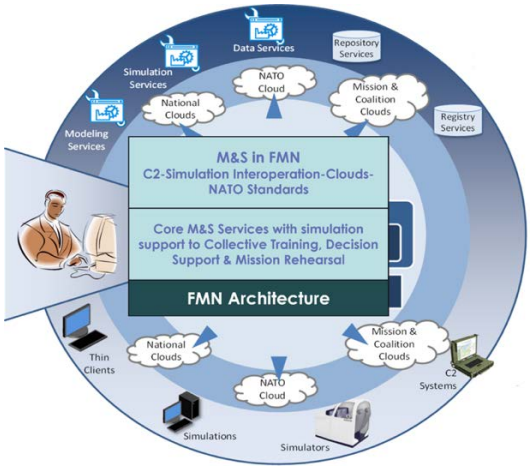


Figure 6. MSaaS in FMN [21]

3.0 MDO SUPPORT IN FMN USING M&S

NATO plans to transform significantly the military operations to move from a joint Command, permission, coordinating operational domains; i.e., "Joint C2" as a layer above C2 units acting per domain (land, sea, air, space and cyber) to a multi-domain Command. This transformation of military operations is known as Multi-Domain Operations (MDO) and will be underpinned by:

- Digital Transformation (DT) which will by 2030 enable the Alliance to conduct MDO, ensure interoperability across all domains, enhance situational awareness, and facilitate political consultation and data-driven decision-making. A 'Digital Backbone' is the foundation for DT.
- FMN, which needs to be aligned to NATO's DT and MDO Concept. At its 14th meeting, the FMN Management Group decided to finalize a strategy to guide the achievement of MDO and FMN Milestone 3 by 2030. Milestone 3 is still, as defined in the NATO FMN Implementation Plan, "a single common infrastructure for all concurrently existing mission networks and their multiple levels of security classification." Anticipating the approval of this strategy, the FMN 2023 Spiral Specification Roadmap will cover interoperability requirements for MDO and Zero Trust Architecture (ZTA) in the upcoming spirals.

NATO and the Alliance members have committed to be MDO enabled by 2030. The MDO roadmap to mature interoperability and standardization will inevitably need to adapt. NATO defines MDO as "The orchestration of military activities across all operational domains and environments, synchronized with non-military activities to enable the Alliance to create converging effects at the speed of relevance". (Approved 16 Jan 2023). MDO is aligned to NATO C2 Concept show in figure 7 below. Its cope is shown at figure 8.

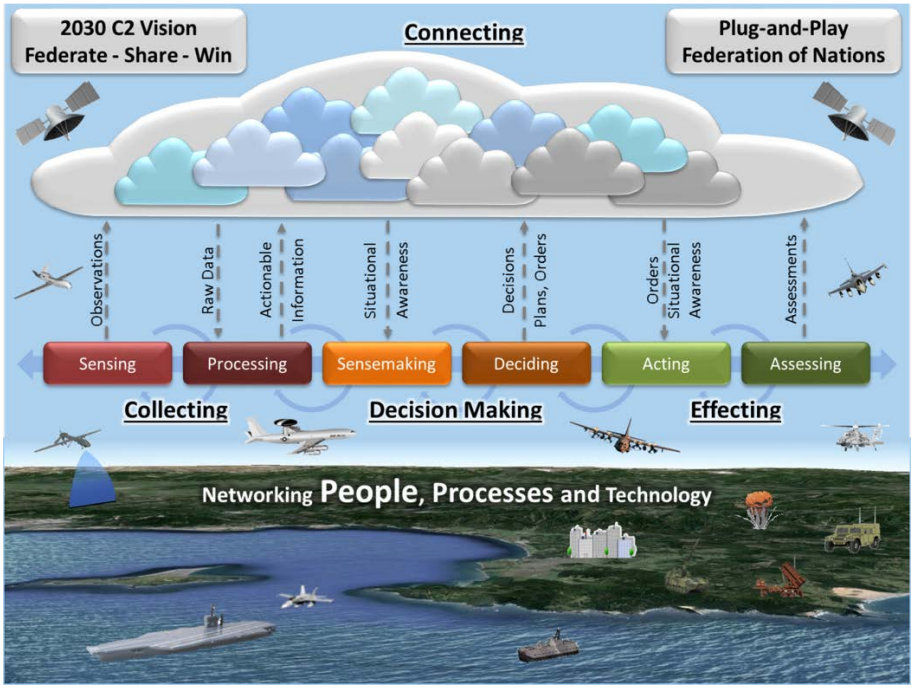


Figure 7. NATO C2 Vision [21]

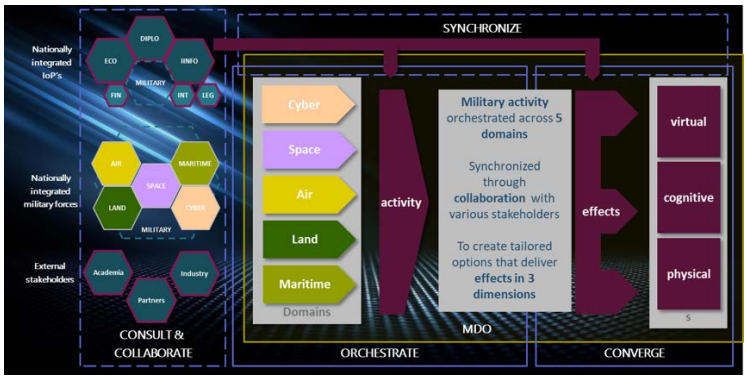


Figure 8. Elements of MDO

Modelling and Simulation is seen as an enabler for MDO and expected to be supported by DT as illustrated by the diagram in figure 9 that was presented in January 2023 at a DT Workshop at ACT.

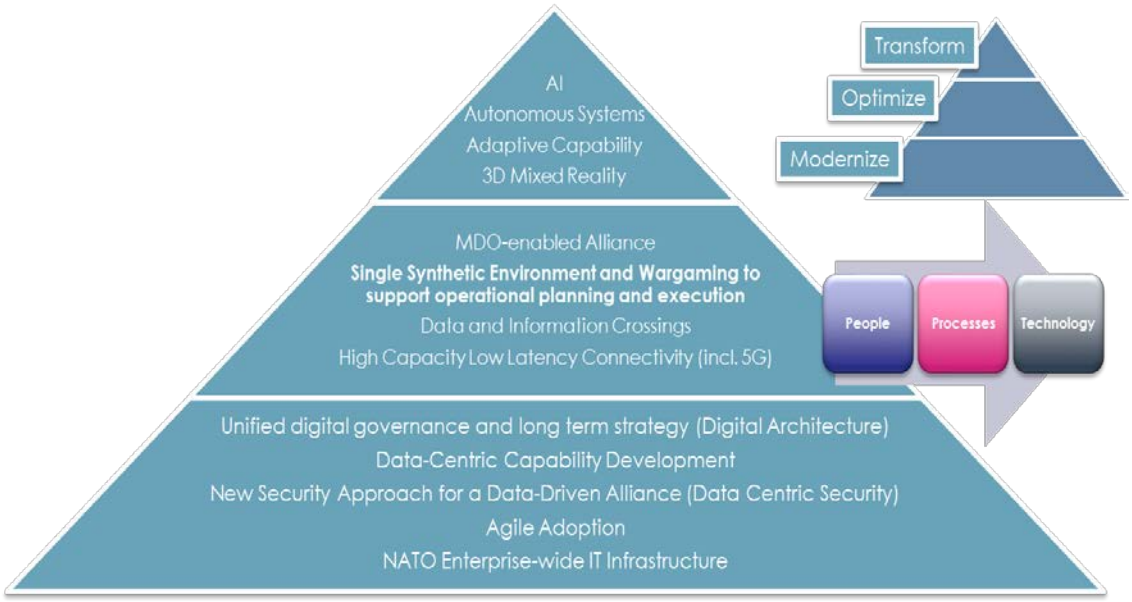


Figure 9. Digital Transformation in support of MDO

It is recognised however that for M&S to support the aspiration of a "Single Synthetic Environment and Wargaming to support operational planning and execution" in a MDO enabled Alliance then it requires M&S to demonstrated in the context of MDO and utilise the capability that FMN will provide. This will require that each of the domains—Land, Maritime, Air, Space and Cyber—will need to be represented in our simulations which may require additional extension to support those domains in the C2SIM standards. This will not only be essential for conducting course of action analysis, wargaming, and mission rehearsal (the current scope of M&S in FMN) but also in collective training where realistic training for what a future battlefield will look like in modern environments characterized by large-scale combat operations that the current conflict in Ukraine illustrates will need to be provided. Headquarters and units at all echelons will need the ability to see themselves in all domains on the battlefield to understand how to operate both offensively and defensively across all domains. [22]

4.0 CWIX 2023 TESTING OF M&S FOR FMN PROPOSAL

MSG-201 supported CWIX 2023 with combined teams from France, Germany, JFTC, Netherlands, Norway, Sweden, and the USA, located partly at the JFTC main CWIX site and partly online via virtual private network (VPN). Testing was based on the SI for M&S, which provides a detailed description of how the proposed M&S standards for FMN interoperate with each other and with operating command and control information systems, to implement the interactions specified in the PI for MR [23]. The testing regimen was laid out in a Federation Agreements document [24].

4.1 Approach to CWIX testing: objectives, test cases and test plan

The overall goal of the MSG-201 team for CWIX 23 was to assess the maturity of the various M&S standards in preparation for their future formal validation in the FMN spiral development process. To build a coherent test plan for our activities, the standard CWIX methodology for the development of test cases [12] was used. The following test *objectives* were defined, all referring to the SI for M&S and the PI for MR, which are tentatively on the FMN roadmap for inclusion in Spiral 6:

- OBJ-142 eXplore FMN SP 6 M&S SI (HLA requirements) to enable FMN SP 6 PI for Land Mission Rehearsal
- OBJ-143 eXplore FMN SP 6 M&S SI (MSaaS requirements) to enable FMN SP 6 PI for Land Mission Rehearsal
- OBJ-144 eXplore C2 Systems to Simulation Systems Interoperation in accordance with the FMN SP6 SI for M&S
- OBJ-145 eXamine a representative Land Mission Rehearsal for FMN SP6 PI

OBJ-142 aimed to assess the robustness of the sim-sim interoperability standards and their implementations in various software components (simulations and mediationware). OBJ-143 aimed to demonstrate a first implementation of basic "remote control" functionality of cloud-hosted simulations and mediationware. The focus of OBJ-144 was to verify the maturity of several standards-based technical interfaces between simulation and C2 systems. Finally, OBJ-145 aimed to pull all the partners' simulations and C2 systems (see table below) together in a representative Mission Rehearsal scenario.

Table 1. Participating simulations and C2 systems

	Simulation	C2-system
DEU	KORA	SitaWare C2LG
FRA	SWORD	-
NLD	VR-Forces	ELIAS
NOR	SWAP	NORCCIS
USA	VR-Forces	SketchThruPlan
SWE	Pitch ACTORS	SitaWare

Individual test cases were described according to the CWIX test case template [27]. This prescribes concise descriptions of the test procedure:

- its purpose
- required pre-conditions
- the capabilities/systems involved in the test

- their respective roles: *provider*, *mediator*, or *consumer*
- the test steps, including the observed result of each step
- validation criteria to determine the test result in terms of *success*, *limited success*, or *interoperability issue*
- a summary of the overall result of the test

4.2 Results of individual standards testing

In total, 36 test cases were completed:

- 7 tests of simulation interoperability requirements (OBJ-142),
- 4 tests of basic Service Management and Control (SMC) functionality, an essential requirement for the establishment of an MSaaS capability,
- 16 tests of C2-simulation interoperability requirements,
- 9 tests related to the final Mission Rehearsal capability.

With this set of test cases the team was able to test all required technical interfaces between the participating systems. Figure 10 below shows all of these systems, including several mediation components for translation between different implementations of standards, and support tools.

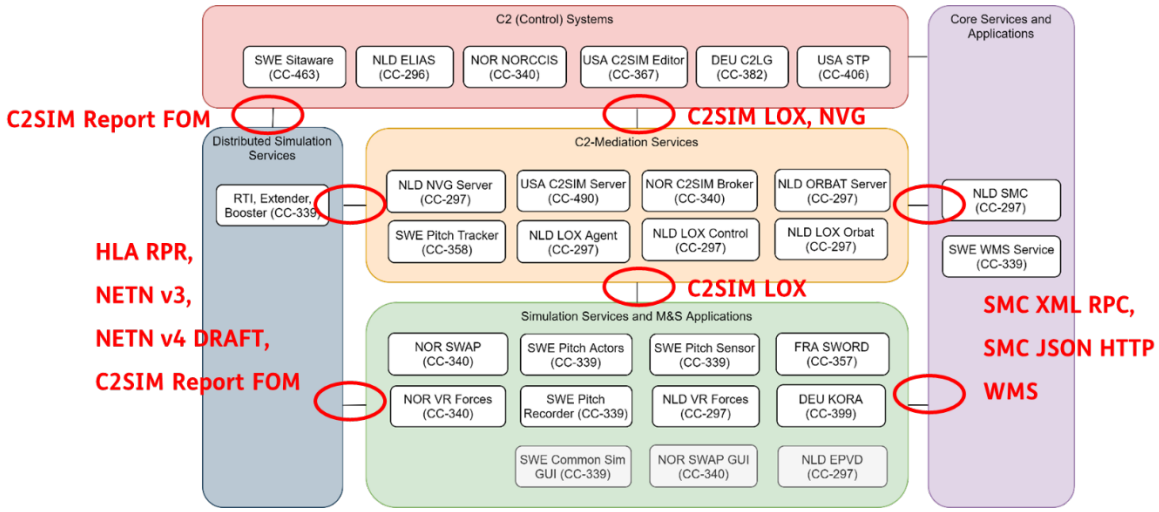


Figure 10. Overview of tested technical interfaces

Execution of the test cases during CWIX 23 resulted in 23 successful tests, 9 cases with limited success, and 4 cases where essential interoperability issues could be identified. Without going into detail, the interoperability issues that we encountered are related to

- implementation of the NETN-ETR elements in some simulations;
- incorrect (or non-) handling of RPR start/stop/pause/resume messages;
- incomplete (or non-) implementation of HLA time-management.

Other issues we found have to do with the mismatch of simulation- or C2-system's capabilities to represent either platform level or aggregate level units. We also found that the PositionReport in the C2SIM standard currently has no provision for "speed" and "heading", which is required in several C2 systems. In spite of the identified issues and shortfalls, these initial interoperability tests provided a sufficiently robust platform to conduct the Mission Rehearsal limited exercise (OBJ-145).

4.3 Results of Mission Rehearsal limited exercise

Mission Rehearsal (MR) is an early operational requirement of the FMN. MR is conducted at all levels of a military organization to ensure Coalition forces understand their role in a planned operation [26]. MR involves the practice of a defined mission in a specific operational context. It can begin after the superior commander and subordinate rehearsing commander(s) have developed their plans and focuses leaders on key execution tasks and the synchronization of combat power to achieve the mission's objectives. An MR covers the actions planned in an operations order (OPORD). It is intended to achieve risk mitigation, not to hone or evaluate skills of participants.

The current PI for MR [23] defines the needs of mission rehearsal prior to deployment that is supported in the land Operational Communications and Information Systems (OPCIS) environment (tactical and joint MR were deferred to later Spirals). It describes the processes required, including the functions of each role, related non-functional requirements, information products, and specific information exchange requirements to be met by FMN. In CWIX 2023, we conducted a limited Mission Rehearsal, aimed at showing how the SI when implemented provides the capabilities specified in the PI.

The framework for testing was re-use of a scenario from CWIX 2022 and earlier [26] where a NATO multinational brigade assists a fictitious nation called "Bogaland" which is experiencing insurgency sponsored by a neighbouring nation. The brigade consists of ground battalions from multiple nations, augmented by a rotary wing air element. The scenario involves suppressing insurgent operations. The scenario operations order provided a realistic context for testing simulation transactions and allowed a Mission Rehearsal focused on deploying the ground battalions in a road march to their new operations areas, and in the process experience a feinting ambush, a typical activity of the insurgents. This limited MR allowed us to experience, in abbreviated form, a testing environment where all systems were required to work together to support an MR. The scenario was adapted from one originally developed for *MSG-145 Command and Control-Simulation Interoperation Standards Support* [26], which conducted similarly distributed CWIX testing in 2019.

We were testing whether the standards and practices specified in the SI, working together, effectively supported Mission Rehearsal as described in the PI. In this context it is important to recognize that, unlike simulation-supported Collective Training, MR simply carries out an operations order under control of unit commander and staff, to familiarize them with the planned operation and allow recognition of aspects that could be problematic. This means that although the simulators worked in a distributed way, they were not interactive, since combat interactions were not simulated because in MR the commander/staff decides who wins, not the simulators. Having tested that the individual transactions would work, the limited MR role players submitted C2SIM representations of the scenario OPORD and observed the simulated results. To help ensure that our MR execution was faithful to actual military operations, our commander/exercise director role player was an active-duty US Army Lieutenant Colonel. The other role players were MSG-201 CWIX team members, several of them active or retired military on the MSG-201 national teams, who in this process both learned more about how MR can be conducted and validated using the performance of coalition simulations.

We tested interoperation of C2 and simulation systems under the standards and practices laid out in the SI for M&S: C2SIM, HLA, NETN-FOM, and cloud-based deployment for M&S services and applications. This was achieved using multiple simulation systems: SWORD from MASA Group (France), VR-Forces from VT-MAK (USA) in NLD MoD cloud, KORA from IABG-GmbH (Germany), SWAP from Norway, and ACTORS from Sweden. Each of these is able to operate under the SI for M&S standards. Some were implemented in cloud platforms, others on individual workstations. Testing also involved C2IS SitaWare from Systematic Software (Denmark) run by Germany and Sweden, NORCCIS from Norway, and Sketch-Thru-Plan system from Hyssos Tech (USA), along with C2SIM editor systems C2LG GUI from Fraunhofer-FKIE

(Germany) and C2SIMGUI from George Mason University (GMU) (USA). The C2SIM Reference Implementation Server from GMU was used by all systems.

In the end, participants were in general agreement that the assembled combination of C2 and simulation systems, interoperating under the recommended standards C2SIM and NETN and supported by cloud computing, should be able to meet the information needs of FMN as specified in the PI. The critique included plans for a more realistic order-creation process for CWIX 2024, including more involvement of individual role-player unit commanders.

5.0 CONCLUSIONS

Federated Mission Networking is an important NATO initiative intended to greatly increase coalition effectiveness through standards-based systems interoperability. Modelling and simulation has much to offer as a force multiplier in the environment, and is likely to prove particularly effective in Multi-Domain Operations. The NATO M&S Group is contributing to the specification of open standards for FMN and testing interoperability of those standards in annual CWIX events.

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