# Preparing for Operational Use of C2-Simulation Interoperation

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## *ABSTRACT*

*Technical Activities in the NATO MSG are completing sustained development of a standards-based capability, known as C2SIM, for coalitions to interoperate their national command and control (C2) and simulation systems collectively as part of NATO's Federated Mission Network (FMN). This form of synthetic battlespace can have a great impact on the effectiveness of coalition military operations. The second generation of C2SIM standards from SISO is ready for balloting and afterwards will form the basis of a STANAG. MSG-145 is conducting extensive testing to validate these standards. Several closely related capabilities developed in testing also can ease the path to operational use.*

*This paper describes those capabilities: (1) C2SIM within Modelling and Simulation as a Service (MSaaS); (2) adoption by the MSCOE of the C2SIM Sandbox distributed development platform; (3) using C2SIM to support operational training in a cyber-active environment; and (4) extension of C2SIM into different domains, exemplified by an Autonomous Systems Extension. C2SIM provides a powerful new, standards-based capability for coalition simulations to support collective training (including cyber effects), planning (including mission analysis) and increasingly important in command and control of Autonomous Systems for military operations. This paper provides important information to prepare for its operational military use.*

## 1.0 INTRODUCTION: C2SIM OVERVIEW

The ability to interoperate command and control (C2 or Mission Command) systems with simulation systems has been an important goal for more than a decade [1]. Over those years the NATO Modelling and Simulation Group (NMSG) has been cooperating with the Simulation Interoperability Standards Organization (SISO) to develop, prototype, and test standards that support that capability. Their shared vision is that members of a coalition will be able to combine their C2 systems and simulation systems collectively into a system-of-systems where simulations are tasked by the C2 systems and in turn provide reports that are displayed on the C2 system just as they would appear due to real-world operations. The resulting system of systems can support training,

course of action analysis, and mission rehearsal for the coalition. Each force element uses the C2 system with which it has trained and is represented by a simulation that represents well its doctrine, resources, and tactics/techniques/procedures. Sharing information this way will result in more effective coalition operations that can happen sooner [2, 3].

Standards enabling the vision described above are well along in development by SISO and expected to reach the balloting phase by the end of 2019. In order to finalize effective standards, the NATO Technical Activity MSG-145 *Operationalization of Command and Control – Simulation Interoperation* (C2SIM) undertook a validation process. This paper describes that process, beginning with the roles and motivations of NATO and SISO, then providing background on C2SIM. After that we will look at the activities of the eight national teams involved most recently and then explain how they enabled validation of C2SIM through a coordinated effort that provided compliant interfaces on six different simulations and one C2 system as well as supporting software. The validation effort took these C2SIM-enabled systems to the NATO Coalition Warrior Interoperability Exercise (CWIX) for detailed testing and then culminated with experimentation, structured as a miniature exercise in distributed mission planning. The paper concludes with lessons learned from the validation process and a view toward the future of C2SIM-based coalition interoperability.

Figure 1 shows the general architecture of a C2SIM coalition. The C2 systems interoperate using a C2 standard; the simulation systems interoperate using a simulation standard; and the system of systems interoperates using C2SIM. A web service is used to replicate C2SIM messages for distribution among the constituent systems and to produce a log that documents results of the operation.

The draft C2SIM standard consists of a text document defining rules and procedures for interoperation and for maintenance of the ontologies; a Core ontology consisting of data classes expected to be needed by any operational simulation; a Standard Military Extension (SMX) with classes applicable to all domains of military activity; and a Land Operations Extension (LOX) to encompass the capability originally provided by MSDL and C-BML and also to serve as an exemplar for future extensions. SMX is logically part of the main C2SIM standard, while LOX forms a new layer on top of Core+SMX.

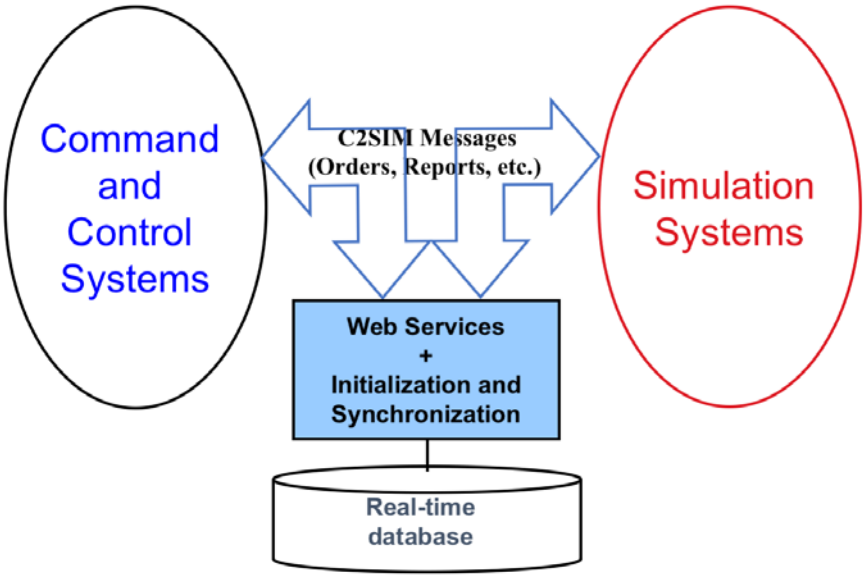


**Figure 1: C2SIM Coalition General Architecture**

## 2.0 NATO AND SISO ROLES DEVELOPING C2SIM

The partnership between MSG-145 and the SISO C2SIM Product Development Group (PDG) has been critical in reaching a point where C2SIM can be validated, and even more critical in the validation process. As a collaborative organization of industry, academic and government people, SISO does not have the ability to develop working prototype systems-of-systems or to validate them with international military participation. Conversely, NATO is not in a position to develop industry-based standards. Cooperative work between the two has been needed to create the C2SIM standard.

MSG-145 is the third in a sequence of NATO Technical Activities that has supported development of C2SIM. The first, MSG-048 *Coalition Battle Management Language*, completed validation of the technical feasibility of coalition C2-simulation interoperation. The second, MS-085 *Standardization for C2-Simulation Interoperation* supported and tested the first generation of C2-simulation interoperation standards: the *Military Scenario Definition Language (MSDL)* [4] and the *Coalition Battle Management Language (C-BML)* [5]. A key outcome of MSG-085 was the determination that while MSDL and C-BML can be made to work together, a second-generation standard was needed to achieve effective harmonization; also that the second generation should be designed for extensibility [6]. SISO responded by forming a merged PDG with a charter to achieve these things under the unified name C2SIM [7]. A goal of MSG-145 is to base a NATO Standardization Agreement (STANAG) on the C2SIM industry standard.

SISO's activities to create C2SIM have been based on a complete bottom-up review of both C-BML and MSDL with a view to the result serving as the basis for a family of extensions. The C2SIM PDG concluded that the best way to approach this was developing a consistent family of ontologies. Development has been underway since 2014 and recently produced a set of draft ontologies that is ready for implementation, along with an approach to extracting a standard XML schema from the ontologies to support implementation for validation.

## 3.0 C2SIM AS A SERVICE UNDER MSAAS

Modelling and Simulation as a Service (MSaaS) is a new approach being explored by the STO NMSG Panel for a permanently available, flexible, service-based framework to provide more cost effective availability of Modelling and Simulation (M&S) products, data and processes to a large number of users on-demand.

The NATO MSG-136 *Modelling and Simulation as a Service Implementation* defined MSaaS as "the combination of service-based approaches with ideas taken from cloud computing" [9].

MSG-145 defined the C2SIM Integration Platform (IP) Reference Architecture (RA) using both the NATO C3 Taxonomy [10] and the MSaaS Reference Architecture from NATO MSG-136 [9] as a source for Architecture Building Blocks (ABBs) and Architecture Patterns. The basic idea is to provide C2SIM as a service, defining ABBs linked to the NATO C3 Taxonomy and the M&S extensions defined by NATO MSG-136. Examples of defined ABBs are Message-Oriented Middleware Service (functionality to support the exchange of messages between data producers and consumers, independent of the message format and content) or Mediation Services (middle layer between incompatible producers and consumers of information), built in the system-of-systems experimented by MSG 145.

An experimental platform to provide "C2SIM as a service" is that developed by NATO Modelling and Simulation Centre of Excellence (MSCOE) in collaboration with the Leonardo company. This is a MSaaS cloud-based testbed prototype, named Open Cloud Environment ApplicatioN (OCEAN). It offers an embryonic framework made of a combination of hardware, software and services to automate the deployment of M&S tools and applications in a cloud environment. The OCEAN platform offers a unique point of access through a web portal with secure access granted by a user identity management system. The availability of services is managed by an M&S services management system that facilitates the delivery, versioning, testing, consumption, termination and disposal of services as shown in Figure 2. The system architecture involves the use of a hybrid cloud where the user can mix use of physical machines, virtual machines and containers (Figure 2) by means of a Platform as a Service solution based on OpenStack installed inside a VMware cluster. OCEAN is expected to provide C2SIM as a Service for experimental purposes by the end of 2019.

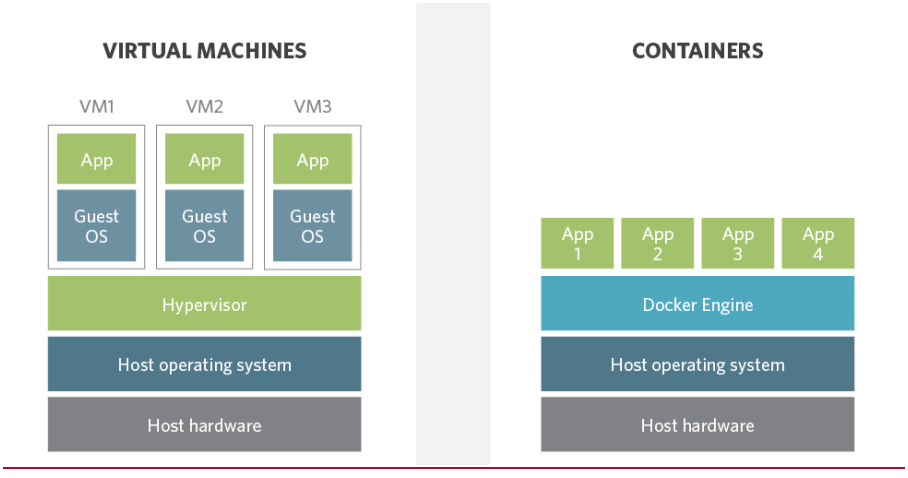


**Figure 2: OCEAN architecture**

## 4.0 TRANSITIONING C2SIM SANDBOX TO MSCOE

Under the MSG-145 activity, an integration and testing environment called *C2SIM Sandbox* was developed by George Mason University (GMU) to provide a full C2SIM capability, available via a virtual private network (VPN) by remote desktop technology, allowing national teams to test and demonstrate any combination of C2 systems, simulation systems, and servers [11].

The C2SIM Sandbox is composed from:

- the BMLC2GUI editor as a surrogate for C2;
- the VT-MÄK commercial combat simulation VR-Forces;
- the C2SIM Reference Implementation Server, open source software developed for the SISO C2SIM standards effort, featuring interoperation with MSDL, C-BML and IBML09 message specifications through schema translation;
- virtual/remote desktop via Web browser, available commercially in open source Apache Guacamole;
- audio/video/whiteboard/chat conferencing open source system Jitsi as a collaboration/conferencing component;
- an open source scheduler for managing shared access to the Sandbox.

The C2SIM Sandbox provides a continually available environment by Virtual Private Network to national teams to test and demonstrate C2SIM. In particular it allows C2SIM testing in the following forms:

- Test C2 with Sandbox Server and Simulation
- Test Server with Sandbox C2 and Simulation
- Test Simulation with Sandbox C2 and Server
- Test C2-Simulation Coalitions with the Server
- Distributed configurations of all sorts

The C2SIM Sandbox has been via Internet VPN from the GMU C4I and Cyber Center since 2017. By the end of the 2019 it will be deployed also at MSCOE and at least part of it will be available at MSCOE as an MSaaS container in the OCEAN platform implementing the C2SIM as a Service concept. Migration of the C2SIM Sandbox to MSCOE is part of the completion of the MSG-145 technical activity handover to NATO, to allow C2SIM testing and experimental use to continue towards a more widespread operational C2SIM adoption.

## 5.0 CYBER EFFECTS EMULATION USING C2SIM

There are two general areas of training for cyber security: (1) training specialized to cyber operations and (2) regular military operational training that applies to a cyber-active environment. The C2SIM Reference Implement Server supports to the latter, which is quite important because military forces must be prepared to function effectively in a cyber-active environment. The GMU C4I & Cyber Center's latest work [8] makes it possible to apply to C2SIM messages many of the effects of cyber and electronic warfare attacks to operational training. This is done by modifying the C2 messages that flow through the C2SIM server, as shown in Figure 3.

The significant difference between Figure 1 and Figure 3 is the addition of a cyber effects editor and an exercise driver that work together to impose cyberspace electromagnetic activities (CEMA effects) on the C2 message stream, creating the effect of a cyber-active environment. While this idea is not new, its impact can be greatly expanded when employed in a standards-based coalition environment. In previous implementations of this concept, it was not possible to emulate cyber effects in associated C2 systems or in the supporting networks of various members of a coalition of such systems operating under the MSDL/C-BML standards, without modifying all C2 and simulation systems involved.

By imposing cyber effects in the simulation, it is possible to achieve a wide range of training stimuli across a coalition without compromising any C2 systems or adding functionality to simulation systems. This can be achieved in environments as simple as a single pairing of C2 and simulation, more complex environments such as in joint training with each component having its own C2 system and simulation, or the even more complex environment in a coalition where several nations are involved, each with one or more C2 systems and simulations. An early test of these concepts was completed by MSG-145 in CWIX 2019 [3].

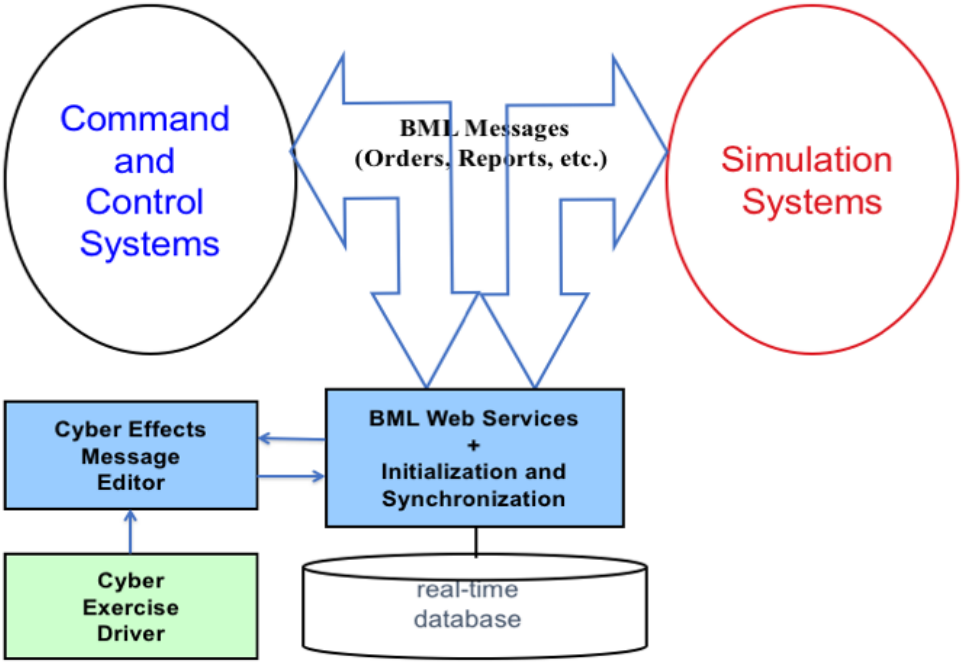


**Figure 3: C2SIM architecture with cyber effects imposed on C2 messages**

## 6.0 EXPANDING C2SIM: THE AUTONOMOUS SYSTEMS EXTENSION

C2SIM is intended to provide a standard for expressing and exchanging Command and Control (C2) information between C2 and robotic and autonomous systems (RAS) in any context. MSCOE has concentrated its efforts on such systems in the coalition context, developing for MSG-145 the use case of the Autonomous Systems (AS). The Autonomous Systems eXtension (ASX) was developed and tested, adding another layer of data classes on top of C2SIM core+SMX+LOX addressing the specificity of the AS domain.

The AS use case was developed by MSCOE in the framework of their "Research on Robotics for Concept and Capability Development" (R2CD2) project, whose aims were to concentrate on: the interaction between Simulated UAxS and real C2 systems; studying the Unmanned Autonomous Systems (UAxS) employment in a megacity of the future (for land and air domains); and Decision Making support for robots using Artificial Intelligence (AI), implementing this Autonomous Function in an external system or in the robotic platforms depending on their level of autonomy. To do this, MSCOE reused the Level of Autonomy (LoA) concept from NATO Allied Command for Transformation (ACT) and the "Archaria" urban model of a megacity of the future from ACT Urbanization Project (UP).

The process for the ASX definition started with the search for its requirements, using a scenario-based methodology delineated in the SISO Guidelines for Scenario Development (GSD) [12]. An operational scenario was designed, based on the simulation objects of the R2CD2 project. Then a conceptual scenario was derived from it, describing the actors, their interactions and flow of actions formally, making use of the NATO Architectural Framework (NAF). Most important, the information exchange requirements (IER) of the scenario were set. The IER was the main source for requirements of new data classes necessary for orders, reports and initialization information to execute the scenario and to build the ASX.

The second step involved the definition of the ASX ontology based on the found requirements. For this goal the Protégé software [13] was employed, extending the objects, data and their properties contained in the basement made by the core+SMX+LOX ontology. The SISO C2SIM PDG guidelines were followed, avoiding repetitions and definitions of elements not peculiar to AS domain. After adding the ASX ontology to this, the standard SISO C2SIM XSLT was applied deriving the ASX XML schema. When the ASX schema was tested in the execution of a scenario, it was demonstrated to be possible to build all the necessary C2SIM messages. It is noteworthy that the described process for schema development is a dynamic one; it automatically includes any changes in the core+SMX+LOX schema, based on the scenario requirements), and also modifications in the ASX ontology, when the schema is produced. Figure 4 summarizes the process.

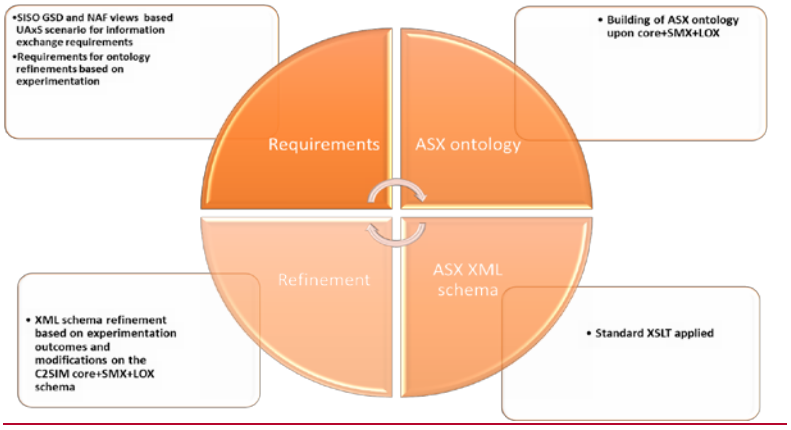


**Figure 4: ASX development process**

## 7.0 CONCLUSION: C2SIM IN OPERATION

The work of NATO MSG-145 and SISO C2SIM PDG has developed a new tool for coalition training, course of action analysis, and mission rehearsal and confirmed its readiness for use. The GMU C4I and Cyber Center and NATO MSCOE have advanced these activities by collaboratively building and supporting open source software: the BMLC2GUI Editor and the C2SIM Reference Implementation Server, that have made this implementation and testing much more productive. GMU also has developed a prototype cyber effects capability for the server and MSCOE has developed and prototyped a forward-looking Asynchronous Systems Extension for C2SIM. These systems show great promise for continuing to accelerate development and deployment of C2SIM for operational use in NATO nations' C2 and simulation systems.

## REFERENCES

[1] Sudnikovich, W., J. Pullen, M. Kleiner, and S. Carey, "Extensible Battle Management Language as a Transformation Enabler," in SIMULATION, 80:669-680, 2004

[2] Pullen, J., B. Patel, and L. Khimeche, "C2-Simulation Interoperability for Operational Hybrid Environments," NATO Modelling and Simulation Symposium 2016, Bucharest, Romania

[3] Pullen, J., B. Wardman and J. Ruth, "Experimental Evaluation of a Command and Control – Simulation Interoperation Standard in a Coalition Environment," *International Command and Control Research and Technology Symposium 2019*," Baltimore, MD November 2019

[4] Simulation Interoperability Standards Organization, *Standard for: Military Scenario Definition Language (MSDL)*, 2009

[5] Simulation Interoperability Standards Organization, *Standard for: Coalition Battle Management Language (C-BML)*, 2012

[6] NATO Collaboration Support office, *MSG-085 Standardization for Command and Control – Simulation interoperability: Final Report*, July 2015

[7] Simulation Interoperability Standards Organization, *Product Nomination for Command and Control Systems – Simulation Systems Interoperation*, July 2014

[8] Pullen, J. and J. Ruth, "Training Operational Military Organizations in a Cyber-active Environment Using C2-Simulation Interoperation," *International Command and Control Technology Symposium 2018*, Pensacola, Florida, November 2018

[9] NATO Collaboration Support office, Operational Concept Document (OCD) for the Allied Framework for M&S as a Service, ST-TR-MSG-136-Part-III, 13 May 2019

[10] NATO Publications, *C3 Taxonomy Perspective, Baseline 2.0*, 1 August 2018

[11] Pullen, J., L. Khimeche and K. Galvin, "C2SIM in CWIX: Distributed Development and Testing for Multinational Interoperability," *NATO Modelling and Simulation Group Simposium 2018*, Ottawa, Canada, October 2018

[12] Simulation Interoperability Standards Organization, *Guideline on Scenario Development for Simulation Environments*, 10 May 2018

[13] Stanford University, *Protégé: A free, open-source ontology editor and framework for building intelligent systems*, https://protege.stanford.edu, accessed 11 Aug 2019