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POTENTIAL Titles:
A Distributed Development Environment for a C2SIM System of Systems

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Abstract

Over the past ten years, a new approach to integrating coalition command and control (C2) systems with simulations into a complex system of systems has been developed into a standards-based environment called C2SIM, with the result that each nation uses the national C2 system with which it has trained and its forces are represented by a national simulation built around its capabilities and doctrine. The C2SIM community has worked out an approach to distributed system-of-systems development that is well suited to the challenges we face: a VPN with facilities available 24x7 for testing and demonstration. This capability enables any national team or combination of teams to test or demonstrate any of the component systems: C2, server, or simulation. Dubbed "C2SIM Sandbox," this new capability is already the basis for multiple development and demonstration plans. The paper describes the design, implementation, and application of the Sandbox.

Keywords: command and control, simulation, interoperability

1. Introduction

Over the past ten years, a new approach has been developed to integrate coalition command and control (C2) systems and simulations into a complex system of systems. Teams from eight NATO nations have worked together toward a vision that a coalition will be able to assemble such a complex system rapidly in a standards-based environment called Command and Control – Simulation Interoperation (C2SIM), with the result that each nation uses the national C2 system with which it has trained and its forces are represented by a national simulation built around its capabilities and doctrine [1]. The resulting technology is being developed under auspices of the NATO Modeling and Simulation Group (NMSG) and standardized by the Simulation Interoperability Standards Organization (SISO) [2]. This emerging capability is now working toward military operationalization. More details can be found in [1] and [19-22].

Integration and testing has been a significant challenge in developing C2SIM. Initially, a schema developed by one team led by the author was exchanged among the participating national teams. This formed the basis for quarterly integration and testing sessions where all teams assembled at a common location. Given the style differences among national teams involved, this process was both technical and social in nature and clearly was necessary in order to arrive at an integrated whole. However, it proved very expensive in terms of developer travel and the cost seemed likely to increase as the schemata involved became more complex during the standardization process. In response, a style of Internet-based development and testing was arrived at, consistent with the fact that the intended product was designed for distributed operation in a networked environment. The new style started as a virtual private network (VPN)

enclave where any of the national teams could work with the same server to test and/or demonstrate C2SIM functionality. That environment has expanded to become the subject of this paper, where a full C2SIM capability is available over the VPN by remote desktop technology, allowing national teams to test and demonstrate any combination of C2 systems, simulation systems, and servers in the “C2SIM Sandbox”.

The remainder of this paper is organized as follows: Section 2 provides an overview of the NATO activities that produced the current C2SIM technology. Section 3 describes the current SISO standards for C2SIM as well as those under development, as the background against which distributed test and demonstration is needed. Section 4 describes the evolution of integration and testing in three NATO MSG Technical Activities. Section 5 describes the architecture and components of the C2SIM Sandbox that has been developed to support these activities; Section 6 concludes the paper.

2. NATO C2SIM Activities

The need for C2SIM interoperation is particularly acute in coalitions. Differences among coalition partners’ C2 systems make use of a single system impractical while differences in organization, equipment, and doctrine result in a situation where each national simulation system may represent only the sponsoring nation’s forces well. Since 2005 a group from the NMSG has been working toward this shared vision [2]:

> *The year is 2025, and somewhere in the vicinity of the North Atlantic a need has arisen for a military force to perform a peacekeeping mission. NATO has agreed to deploy a Multinational Brigade for this mission, and three of its member nations have agreed to provide forces. The designated military organizations promptly connect their command and control (C2) and simulation systems over a secure network and begin training together for their new, common mission. Each nation’s forces are commanded by their own C2 system, which they understand well from long experience; also each nation’s forces are represented in virtual engagements by their own simulation, which reflects accurately their personnel, equipment, and doctrine. As a result, the coalition force is able to prepare rapidly for its new mission, learning to deal with the unique aspects of each national force while preparing those forces to work together toward their shared mission.*

The NMSG has organized a sequence of Technical Activities to work toward this vision.

2.1 Exploratory Team ET-016

ET-016 grew up around cooperative efforts between groups from France and the USA to chart a possible path forward for C2-simulation interoperation technology, which at that time was known as “Battle Management Language” (BML). They cooperated to provide the first initial example of successful international C2SIM integration using a

BML approach [3, 4] and were joined by several other nations in developing a plan to evaluate the technical feasibility of Coalition BML (C-BML). The general architecture adopted for that work, based on Web Services, is shown in Figure 1. It has continued to be used for succeeding NMSG work in C2SIM.

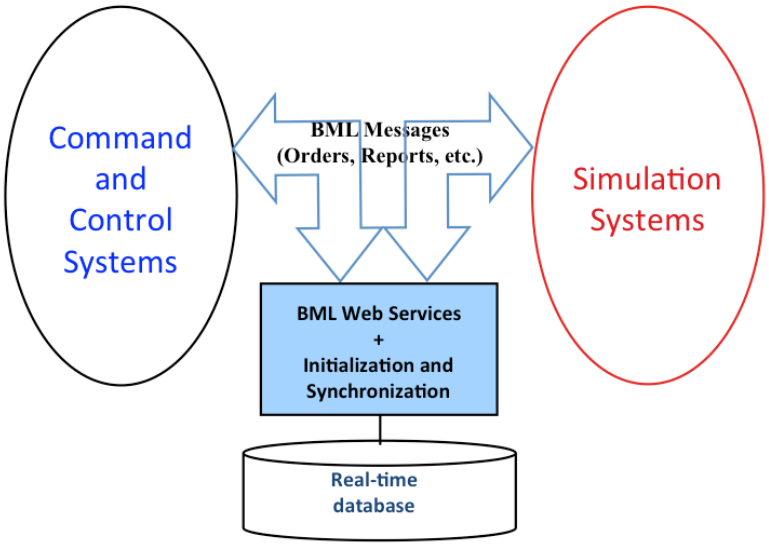

Figure 1: General Architecture for C2SIM

2.2 Technical Activity MSG-048 Coalition Battle Management Language

MSG-048, organized under co-chairs from France and the USA, included national representatives from Canada, Denmark, Germany, the Netherlands, Norway, Spain, Turkey, and the United Kingdom (UK). Its work was conducted in three main areas: establishing requirements for the C-BML standard, assessing the usefulness and applicability of C-BML in support of coalition operations through experimentation, and educating/informing C-BML stakeholders concerning the results and findings of the group.

2.3 Technical Activity MSG-085 Standardization for C2-Simulation Interoperation

MSG-085 followed MSG-048. It was focused on assessing the operational relevance of Coalition BML while increasing its Technical Readiness Level (TRL) to a point consistent with operational employment. France chaired and Canada was designated as co-chair. Nations participating included the original ones from MSG-048 plus Belgium and Sweden. Increased focus on operational relevance required more participation from operational military and their support staffs, which were recruited by the participating national teams.

The Final Demonstration of MSG-085 took place at Fort Leavenworth, Kansas in December, 2013. MSG-085 partnered with the US Army Mission Command Battle

Laboratory, first engaging in a short integration session. The featured capability was Joint and Combined Mission Planning [5,6]. The architecture of the demonstration system-of-systems that was assembled is shown in Figure 2. In addition to establishing the operational relevance of the approach, this demonstration showed that the technology used had achieved a greatly improved TRL. This was shown by expeditious integration of the various systems used and also by a capability for operation over the Internet. The MSG-85 final audience got the message “We have an exciting new capability and it works very well to improve some unmet needs of coalition C2, using interoperable simulations.” MSG-085 finished its work in 2014 [7].

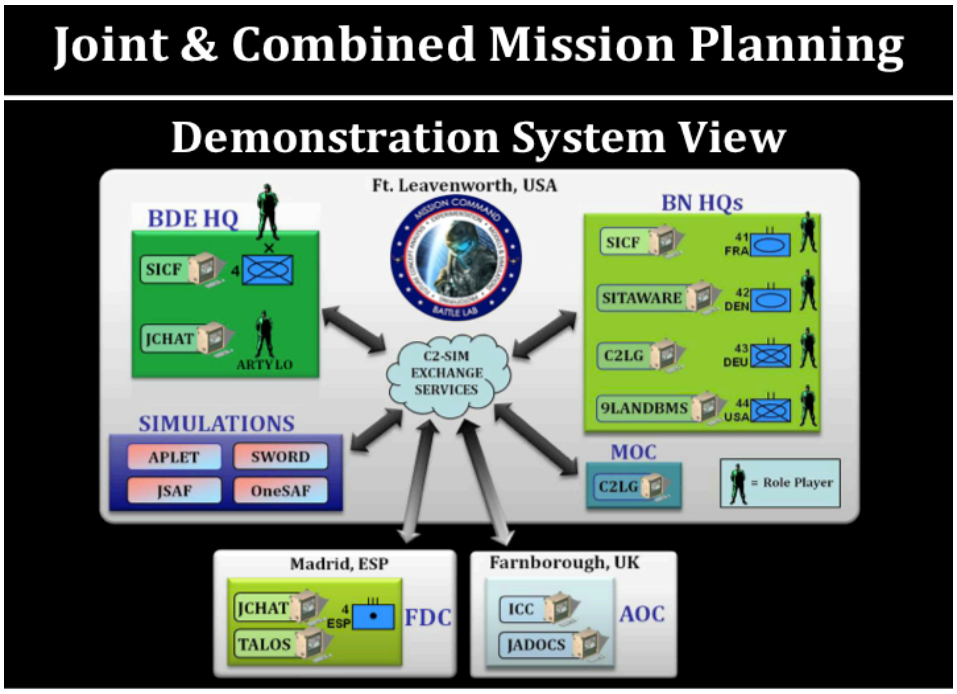

Figure 2: MSG-085 Final Demonstration System of Systems

2.4 Technical Activity MSG-145 Operationalization of Standardized C2-Simulation Interoperability

MSG-145, now in progress, is focused on bringing C2SIM to the attention of military operators and assisting them in adopting it [8].

3. SISO C2SIM Activities

SISO’s mission is to develop, manage, maintain, and promulgate user-driven Modeling and Simulation (M&S) standards that improve the technical quality and cost efficiency of M&S implementations across the world-wide M&S community. SISO seeks to foster the open exchange of information and technologies to support the advancement and

standardization of M&S-related technologies and practices. Its work is done by companies (or other organizations) and by individuals volunteering their efforts.

3.1 First Generation Standard: MSDL and C-BML

SISO's development of C2SIM standards began with two loosely coupled, parallel efforts to standardize the technologies described above as used by MSG-048 and MSG-085. These were the Military Scenario Development Language (MSDL) [9] and the Coalition Battle Management Language (C-BML) [10]. MSDL provides for consistent initialization or start data for both C2 and Simulation systems participating within a Coalition. The object standardized by MSDL is the *scenario file*, which provides a specific description of the situation and course of action at a moment in time for each element in the scenario. C-BML grew out of a US Army experiment that sought ways to replace the natural language of battlefield C2 with an unambiguous language that can be used as input to software [11]. The C-BML standard defines standard XML data composites for tasking (orders and requests) and reports. We refer to the combined C2SIM system of systems as a *Coalition*.

An important finding of MSG-048 was that, for an effective operational capability, the SISO C-BML focus on Orders, Requests and Reports needs to be supplemented with initialization via MSDL in order to address the full scope of C2SIM. Therefore MSG-085 members implemented MSDL in the simulation systems they had made BML-capable under MSG-048. This implementation was effective but it illuminated another problem: although SISO policy called for MSDL and C-BML to work together, the two were developed independently and there was no "roadmap" telling how to use them together. As a result, considerable effort went into exploring alternatives before a path forward was adopted [12-14].

3.2 Second Generation Standard: C2SIM

MSG-085 successes in demonstrating technical and operational relevance built considerable experience that helped in completing the C-BML Phase 1 standard. However, MSG-085 also produced some clear results [15] indicating a need for more work by SISO. MSDL and C-BML were developed separately and are less than perfectly suited to working together; an integrated standard is needed. Also, C-BML Phase 1 requires extension in order to be used for the full spectrum of military operations.

MSDL and C-BML each had been intended to move forward to at least one more version. The Product Development Groups responsible for the two standards saw significant benefit in combining their efforts in the second phase of each. They therefore proposed a new, unified effort to replace the second phase of MSDL and C-BML: a single C2SIM Product Development Group for C2-simulation interoperation, to include

other systems dependent on the same information (e.g. autonomous or robotic systems), which is planned to consist of three documents:

- C2SIM Standard: This consists of the logical data model (LDM) that provides the logical definitions of initialization, tasking, and reporting business elements and associations referenced in the syntactic representation standards of C2SIM, along with procedures and message flow for initialization and tasking/reporting.
- An example extension to the LDM, for Maneuver Warfare. This will serve as an exemplar of C2SIM extensions and also will round out the second-generation standard to include a capability similar to that embodied in MSDL and C-BML.
- A guideline document for implementing C2SIM.

4. Distributed Development in NATO C2SIM

Starting with ET-016 and continuing through the present, NMSG activities in C2SIM have been faced with the problem of integrating and testing software developed by several national teams into a coherent system of systems that can support experimentation and demonstrations. While adopting a Web Service architecture and a well-coordinated sequence of schemata facilitated this, problems of technical and cultural adaptation among multiple national teams remained, due to the fact the software systems and their developers had not previously worked together. Initial response to these problems was to periodically co-locate the teams for integration and testing. This was an expensive approach because of travel involved and it necessarily constrained the time available for integration and testing to a tight schedule. For MSG-048, this caused difficulties in that a planned week of final integration at Portsmouth, UK, proved insufficient so that an extra week in Paris, France had to be scheduled on short notice. Even after this extra time, the MSG-048 Final Experimentation began with some systems not interoperating; in fact the whole system-of-systems became fully functional only on the last day of experimentation. (The operational military who participated in the experimentation nevertheless saw great potential in C2SIM and encouraged its continued development.)

In order to facilitate continued integration during MSG-085, a VPN was established over the Internet, available to all participating national teams, providing continuous access to instances of both of the C-BML/MSDL servers used in MSG-085. National teams who needed to test C2 and simulation systems could schedule use of this facility, typically by two or three teams testing together. In this way, many integration problems could be resolved without travel. Combined with the evolving maturity of MSDL and C-BML implementations, this resulted in a much more coherent process when MSG-085 teams came together for a final week of testing at Copenhagen in October 2013 before the final demonstration. Some problems remained but the participating teams left that week with a solidly functional C2SIM system-of-systems. On reassembling at Fort

Leavenworth, Kansas in December, 2013 there were a few minimal problems due to last minute changes but the observation was that the system of systems “plugged together and worked.”

As an example of the complexity dealt with in MSG-085, it is instructive to consider the server system. The final demonstration used distributed servers to provide more processing power and communication efficiency. As shown in Figure 3, the system was heterogeneous, consisting of the FKIE server from Fraunhofer FKIE and the WISE-SBML server from Saab Corporation and George Mason University (GMU) [16]. Because development had proceeded piecemeal before availability of the VPN testing environment, four related but different schemata were potentially in use. The FKIE server supported an FKIE-extended “IBML09+” version of the schema from MSG-048 [17], while the WISE-SBML server supported, and could translate among, IBML09, IBML09+, and the two subschemata of the SISO C-BML standard (although, as it turned out, only the “light” version of C-BML was used). Translation required that the WISE-SBML server parse each C-BML order and report and reformat them to comply with the various schemata. Such complexity would have been unsupportable during MSG-048, four years earlier.

Since C2SIM is moving forward to extensible schemata and yet will still need backward compatibility to the MSG-085 systems, the new MSG-145 Technical Activity is faced with an ever more pressing need to integrate a variety of systems. National teams need to be able to test their systems individually in a distributed fashion and in subgroups. At the same time, MSG-145 has a need to be able to demonstrate a functioning C2SIM Coalition to military operators whenever requested. MSG-145 concluded that a more complete distributed development environment, including at least one C2 system, one server, and one simulation, should be continually available. This system-of-systems should be capable of interoperating with any other C2SIM-compliant system and displaying the results through a web browser as a remote desktop. It should include facilities for scheduling its use and for network-based collaboration among participants during operation. If it meets all these requirements, it will also have the ability to be replicated to multiple nodes on the VPN or as multiple testing/demonstration environments.

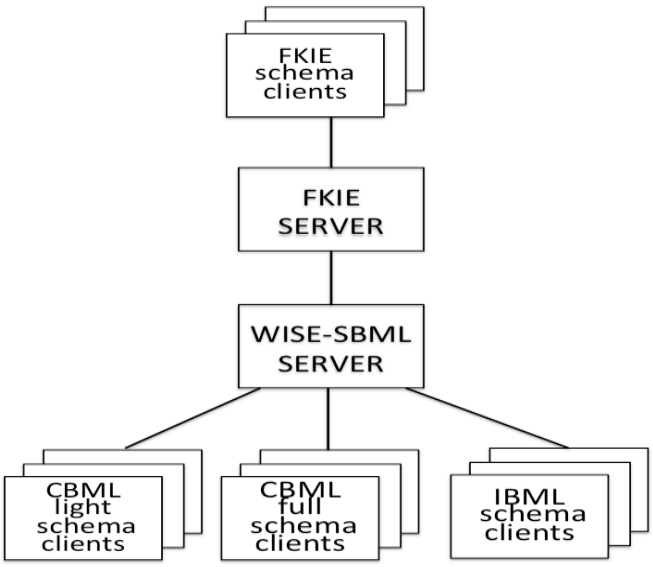

Figure 3: MSG-85 Linked Server Architecture.

5. C2SIM Sandbox Distributed Testing and Demonstration Environment

The GMU C4I and Cyber Center has undertaken to assemble for NATO MSG-145 a "C2SIM Sandbox" testbed for C2SIM, meeting the description above. This is a continually available environment, available by VPN to national teams to test and demonstrate C2SIM. It supports C-BML and MSDL, and also will support new SISO C2SIM core when definitionof that is available, including an implementation of the draft extension standard for Maneuver Warfare, including all the capabilities used in MSG-085 for orders and reports. In addition to these functions, the C2SIM Sandbox will build experience toward a future "C2SIM as a Service" capability [18]. Also it is envisaged that the C2SIM Sandbox will serve as the nucleus of a distributed testbed operated for MSG-145.

The C2SIM Sandbox will employ one or more C2 systems and commercial combat simulations, along with a server, operating in a virtual computing environment. Initially the Sandbox will support the MSG-085 schemas, interoperating through a translating server. After these functions are operational, other C2SIM systems provided by MSG-145 participants and extensions such as autonomous systems can be incorporated.

An important capability employed in the Sandbox is virtual/remote desktop via Web browser, which recently has become available commercially [ref]. This enables remote participants to work with any application incorporated in the Sandbox, using only readily available open source VPN client and any HTML5 compliant web browser. The Sandbox environment uses open source remote desktop gateway software and virtual network computing (VNC) to enable remote interaction with virtual machines hosted within a VMWare vSphere hypervisor as well as actual physical machines. The virtualized environment allows for flexibility in the applications and services made available for testing.

C2SIM Sandbox remote application interfaces are intentionally limited to the user GUI capability of each software system. The Sandbox is able to block inspection of the C2, simulation or server code so that privacy can be provided for software providers. For Windows systems, this is accomplished using a combination of group policy controls to operate the system in a kiosk mode. Instead of physical interaction, it is done remotely through the remote desktop gateway accessed within the Sandbox environment's virtual private network. A similar capability is achieved on Linux systems using a window manager optimized for restricting application access.

One or more pre-packaged scenarios with recorded instructions for operation are planned to be included with the Sandbox, to enable the C2SIM configuration to be exercised with only a minimal understanding of the software. The scenario will be user-modifiable within a limited scope via the C2 system GUI, to allow users to run alternatives and observe results.

The C2SIM server will be a new open-source Java server developed by the GMU C4I and Cyber Center as a reference implementation for the C2SIM LDM Core and Maneuver Warfare extension. This is a further development based the WISE-SBML translating server approach described in [16], which is capable of translating among XML documents based on different schemata if they are semantically-equivalent, which also will be easier to reconfigure. This server therefore wprovides a means of backward compatibility from C2SIM to first-generation BML standards MSDL and C-BML [9][10] as well as interoperability with systems based on NIEM [23] and MIM [24]. Use of Java is intended to make the server more understandable, at the cost of lower performance than WISE-SBML. The server supports logging and replay and is planned to add support for late joiners and checkpoint/restart.

The initial simulation capability in the Sandbox is the VR-Forces commercial military simulation from VT-MÄK. The enable its use in the Sandbox, we have added a C2SIM interface that accepts and parses XML documents containing orders and converts them to commands accepted by VR-Forces. Parsing is accomplished using the commercial open-source Xerces C++ parser.

Another capability provided in the Sandbox will be an open-source Web-application based conferencing system, based on an online education system developed in the GMU C4I and Cyber Center [25]. This will enable voice and graphic communication among Sandbox users without the cost of commercial telephone or conferencing.

Figure 4 shows the architecture of the C2SIM Sandbox, including the C2, simulation, server, scheduling, and collaboration/conferencing components. All of these are intended to be accessed remotely via a Web browser. In addition to interacting with the sandbox components (individually or at multiple remote VPN sites), the systems in the Sandbox are able to interact over the VPN via C2SIM standards with other C2 systems, simulation systems, or server systems.

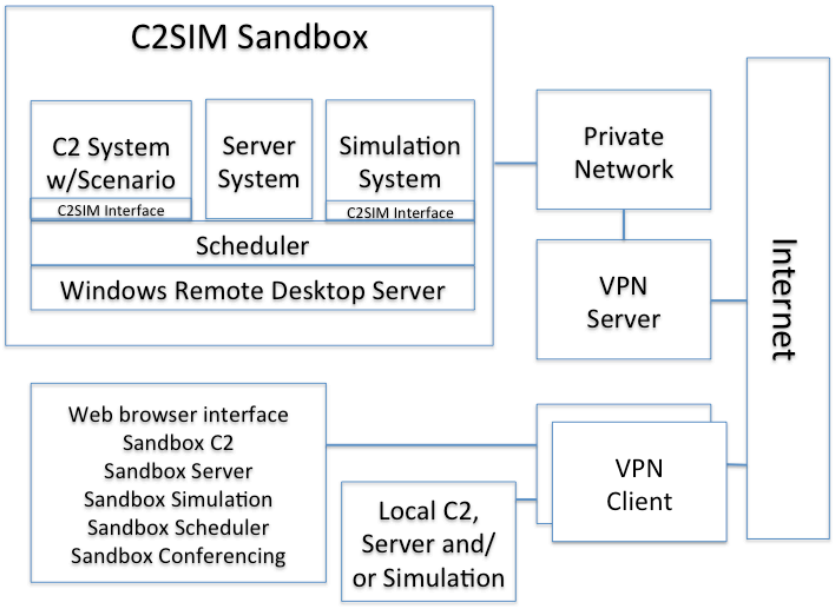

Figure 4. C2SIM Sandbox Architecture

Thus the C2SIM Sandbox is able to facilitate testing and demonstration in a variety of modes:

- C2SIM demonstrations
  - Schemata: IBML09, IBML09+, CBML Light, C2SIM Core
  - C2SIM Maneuver Warfare when available
  - Generic scenario provided (others if contributed)
- C2SIM testing
  - 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
- C2SIM validation with SISO
- C2SIM-based exercises (scope limited by server performance)
- In the future: C2SIM as a Service

MSG-145 is planning to conduct testing and demonstration in multiple events that attract the attention of the operational military. The C2SIM configuration will grow as it proceeds through this sequence: CWIX 2017, NATO CAX Forum 2017, I/ITSEC 2017, Viking18, and CWIX 2018.

6. Conclusions

C2SIM offers a highly promising way to combine command and control with simulation in coalitions, supporting more effective preparation and planning for operations. It has benefitted from multiple NATO Technical Activities and a continuing SISO open standards effort. Integration, testing and demonstration of the NATO technology development and SISO standardization is most effectively and efficiently achieved in a distributed/network-based manner. This paper has described the evolution of distributed testing and demonstration of C2SIM. Development has reached the point where the C2SIM Sandbox supports a complete C2SIM system (C2, server and simulation) along with scheduling and conferencing capabilities, over a VPN. The result is enabling faster, better integration, testing and demonstration of C2SIM in NATO and SISO.

In the future we envision expansion of the collection of C2 and simulation systems available to or through the Sandbox, for example the Sitaware commercial military C2 system from Systematic Software Inc. and also the Joint Semi-Automated Forces (JSAF) that was used with the Sandbox in CWIX 2017. Some of these systems may be hosted remotely by MSG-145 partners on a 24x7 basis or an as-needed basis. Ultimately, the complete C2SIM Sandbox will be documented on our website in sufficient detail to enable its replication either within MSG-145 or elsewhere.

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