# **Coalition Command and Control – Simulation Interoperation as a System of Systems**

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*Abstract*—The Simulation Interoperability Standards Organization (SISO) and the NATO Science and Technology Organization (STO) have since 2005 had activities to interface military command and control (C2) systems with simulation systems. This paper describes a new and highly promising way to combine NATO partners' C2 systems and simulation systems into a system of systems that is capable of supporting military training, course of action analysis, and mission rehearsal for a coalition. Each national force uses its own C2 system and is represented by its own simulation, which best represents its capabilities. The overall coalition will thus be able to come together rapidly to function as an integrated whole.

# *Keywords—command and control; simulation; interoperability; system of systems*

### I. INTRODUCTION

This paper is written to inform the System of Systems Engineering (SoSE) community about a significant new application of System of Systems (SoS) architecture. The subject is the capability to interoperate military simulations with command and control (C2) systems, known broadly as C2SIM [1]. The authors are part of a NATO group that has built two generations of experimental C2SIM systems and is now working on a third generation that is intended for operational deployment. We also participate in a related, supporting open standards effort under the Simulation Interoperability Standards Organization (SISO). These activities have experimented with up to ten simultaneously interoperating C2 and simulation systems, each capable of independent operations. We use the term *coalition* for such a collection of C2 and simulation systems, including supporting services.

Although our principal expertise lies in military C2 and simulation, we have found the emerging area of SoSE to capture knowledge that is relevant to C2SIM. Reference [2] provides broadly recognized characteristics for an SoS that fits our work in this area very well:

- *Operational independence of the elements*: Each C2 and simulation system in a C2SIM SoS is a fully independent, stand-alone system.
- Managerial independence of the elements: Each C2 and

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simulation system in a C2SIM SoS is operated by a different organizational element; typically there will be one C2 system and one simulation per nation and the two will be managed by independent organizations within that nation.

- *Evolutionary development*: While experience with aspects of C2SIM dates back at least to 2003, the concepts and modes of interoperation have continued to evolve and this is likely to continue due to the rapid development of software technology.
- *Emergent behavior*: C2SIM is a technology that continues to emerge, and that will change the nature of the very problem it is intended to solve. As its development has proceeded, we have seen overall system behavior that cannot be predicted or understood from the properties of single elements in the system of systems.
- *Geographical distribution*: Anticipated application will see the systems comprising a C2SIM coalition located in national facilities distributed across the operational space. From the second generation of its development, the SoS has been demonstrated in such a configuration.
- *Interoperability*: This has been the hallmark of C2SIM; it is seen as a means of operating dissimilar systems.
- *Complementarity*: Each system complements all of the other systems within a C2SIM coalition.
- *Holism*: "Holism suggests that we cannot understand a complex system through reduction to the component or entity level" [2] and this is certainly the case for a C2SIM coalition of multiple national systems.

The remainder of this paper is organized as follows: we explain how NATO Modelling and Simulation Group (NMSG) and SISO are working together to achieve operational C2SIM, and how it can make a difference in military operations; then we explain how it is achieved, using message-passing, and how our infrastructure supports this messaging; finally, we describe successful experiments of C2SIM including challenges to understanding C2SIM as an SoS, and draw conclusions.

#### II. NMSG AND SISO

NMSG is one of seven panels/groups under NATO Science and Technology Organization. It has been the principal sponsor for experiments in C2SIM, which necessarily must take place in a coalition environment. Its partner, responsible for codifying open standards based on the results of experimentation, is SISO. The relationship between these two is further described below.

#### A. NMSG C2SIM

Initial NMSG concerns for C2SIM interoperation were largely economic. Modern combat simulations, introduced in the 1980's, enable military organizations to "train as you fight" by using their operational C2 systems to interact with each other and with the simulation [4]. However, interaction with the simulation required an extra human in the loop to transfer C2 information into the simulation system and also enter situational information from the simulation into the C2 system. In a large exercise, staffing for knowledgeable people to play this role became a major expense. Automated interfaces between C2 and simulation systems were implemented in an ad hoc, point-to-point manner and could not be extended readily to other systems. A more generic, consistent approach to interoperability was needed. Adherents to this approach called it Battle Management Language (BML) [5]. Fig. 1 shows the general service-oriented architecture adopted to exchange BML messages. The server provides a publish/subscribe service to its clients. Use of a server-based architecture has two advantages: it simplifies a complex development environment, since each client can be tested individually using the server; and it provides a measure of fault-tolerance, since it does not require that all members of the C2SIM system-of-systems coalition are available at all times.

The need for C2SIM is particularly compelling in military coalitions, because differences among coalition partners' C2 systems and simulations make use of a single system impractical; the national forces are training to use their own C2 systems and are best represented by their own simulations.

Thus, differences in organization, equipment, and doctrine result in a situation where each national simulation system may represent only that nation's forces well. Interest in using BML for this purpose led to a four-year NATO Technical Activity *MSG-048 Coalition Battle Management Language*, led by France and the USA and included national representatives from Canada, Denmark, Germany, the Netherlands, Norway, Spain, Turkey and the United Kingdom (UK). The group developed and evaluated prototypes, working to define solutions that could be standardized by SISO as Coalition Battle Management Language (C-BML – see below). Fig. 2 shows the SoS assembled for MSG-048 experimentation. Each box in the diagram is an independent system; the systems interoperate by passing messages, through the Web services, in a standard format.



Fig. 1. General Architecture for C2SIM, from [5].

Results of MSG-048 indicated that C2SIM was technically feasible; this led the NMSG to charter a follow-on activity *MSG-085 Standardization for C2-Simulation Interoperation*. Fig. 3 shows the SoS assembled for MSG-085 final demonstration; again each simulation and C2 system is an independent system but now the message exchange can itself be a systems of cooperating, independent Web services. The conclusion of MSG-085 was that C2SIM would be operationally beneficial. As a result, the NMSG initiated in 2016 a new activity MSG-145, which is aimed at operational deployment of C2SIM.

#### B. SISO C2SIM

SISO provides a collaborative environment for exchange of information about simulation interoperability and an organization under which standards for interoperability can be developed. A creative synergy has existed between NATO MSG activities in C2SIM and the focus of SISO on standards needed to support C2SIM [7].



Fig. 2. SoS for MSG-048 Final Experimentation, from [6]. The blue and red squares contain the C2 systems for blue and red forces respectively. The gray square contains simulation systems.



Fig. 3. MSG-085 Final Demonstration System of Systems, from [10]

SISO chartered a Product Development Group (PDG) to develop a Coalition Battle Management Language (C-BML) standard in parallel with MSG-048 [8]. An important finding under MSG-048 was that, for an effective operational capability, the SISO C-BML focus on Orders, Requests and Reports must be supplemented with another SISO standard: the Military Scenario Development Language (MSDL) [9] in order to provide effective initialization of systems. Accordingly, in its first year MSG-085 focused on adding MSDL to 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.

The culmination of MSG-085 included a new insight: a more productive path would be to base the next generation of C2SIM standards on a logical data model (LDM), standardizing the core of that LDM and the process for extending it into new domains. Schemata needed for interoperation in various domains could then be derived from the LDM. Also, the second generation of initialization (MSDL) and tasking-reporting (C-BML) should form a single standard, based on that LDM [10]. In September 2014, SISO chartered a unified C2SIM Product Development Group (PDG) and associated Product Support Group (PSG) based on those recommendations. Its work is ongoing and is anticipated to build on experience resulting from NATO MSG-145.

#### III. MESSAGING INFRASTRUCTURE

The basis for all C2SIM interoperation is asynchronous message passing among coalition component systems. To date, in every implementation this has been achieved by sending messages from each component system through a networked server to one or more other component systems. The messages represent standard information exchange among military C2 systems: *orders* and *requests* state that some action(s) need to be taken (orders must be followed if

physically possible where requests are followed at the discretion of the recipient) and *reports* provide information about the results of the orders/requests, including observations made while complying. To date the messages have been in the Extensible Markup Language (XML), following rules for Web services [11]; however, see below for a discussion of possible use of JavaScript Object Notation (JSON).

#### A. XML Messages

The term "Web services" describes a standardized way of integrating Web-based applications using the Extensible Markup Language (XML), SOAP [12] and Web Services Description Language (WSDL) [13] open standards over an Internet protocol backbone. XML is used to tag the data, SOAP is used to transfer the data, WSDL is used for describing the services.

Fig. 4 shows a simple BML report document, coded in XML. XML uses "tags" to describe the data it contains. A *schema* provides a definition of all possible tags for a particular XML document and the order and groupings in which they are allowed. The schema itself is also formatted in XML. There may also be a description of the schema in the WSDL.

XML can be read by a human if necessary, but it's not a very pleasant process. For example, in Fig. 4 the unit reporting is "1-22" and it is reporting something about a Friendly unit (in fact, about itself, because it also is the "executer"). XML is often called "verbose" because the tags take up so much space in the message.

• </th <th>xml version="1.0" encoding="UTF-8"?&gt;</th>	xml version="1.0" encoding="UTF-8"?>
• <b< td=""><td>MLReport</td></b<>	MLReport
• xn	nlns:jc3iedm="urn:int:nato:standard:mip:jc3iedm:3.1a:oo:2.0
۰xn	nIns:bml="http://netlab.gmu.edu/IBML"
۰xn	nIns:msdl="http://netlab.gmu.edu/JBML/MSDL">
•	<report></report>
•	<categoryofreport>StatusReport</categoryofreport>
•	<typeofreport>GeneralStatusReport</typeofreport>
•	<statusreport></statusreport>
•	<generalstatusreport></generalstatusreport>
•	<reporterwho></reporterwho>
•	 shillo>1-22
•	
•	<hostility>FR</hostility>
•	<executer></executer>
•	  bml:Taskee>
•	<pre><bml:unitid>1-22</bml:unitid></pre> /bml:UnitID>

Fig. 4. Example XML Report.

#### B. JSON Messages

The current SISO C-BML and MSDL specifications mandate the use of XML to represent C2SIM messages. XML is a widely preferred means of exchanging data between systems. In addition to being widely supported, XML also provides schemata that allow validation of the structure and to some degree the contents of XML documents. JSON [14] is however gaining popularity especially in Web applications where JSON is much more convenient to use than XML. JSON is a text format for representing structured data as attribute-value pairs and is based on a subset of the JavaScript language.

The introduction of HTML5 enabled developing advanced Web applications that are multi-media rich. In the simulation domain WebLVC [15] is an emerging SISO standard that extends distributed simulation to include the Web browser as a component. C2SIM applications may also benefit from modern Web technology, enabling rapid development and deployment of user applications. [16] and [17] reports on simulation supported military planning capabilities that use Web technology. An example BML task formatted in JSON used in [17] is shown in Fig. 5. In this example a mechanized infantry company ("taskeeWho") is tasked to seize ("what") an area ("where") starting after another task is being completed ("when").

"type": "BmlTas	k",	
"who": {		
"taskerWho":	{	
"name": "SW	AP"	
},		
"taskeeWho":	{	
"name": "ME	K INF",	
"id": "776e	26f9-6a0e-41ff-ae65-98d798592ee2	
1		
}. <sup>3</sup>		
"what": {		
"activityCode	": "SEIZE",	
"remark": ""		
}.		
"where": {		
"type": "Msd](	ControlMeasureWhere".	
"controlMeasu	reBef": {	
"id": "6DF4	F4FF3219465386D9932840F47A34"	
1		
, }.		
"how": {}		
"when": [		
"type", "Tack	When"	
"minimumDurst	ion": pull	
"aatimatadDura.	-+	
"maximumDupat	ion": 1/4/5//.14/4555410,	
	-"- (	
startiaskwhei	n : (	
type : Sta	artwhenkelativelime ,	
reterenceu	uration : 0,	
"temporalRe	†": { 	
type :	TaskRet ,	
"id": 25		
},		
"temporalAs:	sociationCategoryCode": "STREND"	
},		
"endTaskWhen"	: null,	

Fig. 5. Example BML Task formatted as JSON.

#### C. Transfer Protocols

Inputs to a Web service are carried over the Internet standard Hypertext Transfer Protocol (HTTP), coded in the SOAP with a connection made new for each transaction. However, SOAP was designed for remote procedure call (RPC) to the Web service and that is normally not needed for BML. As a result it is common to replace SOAP with the Representational State Protocol (REST), which requires less processing.

In a C2SIM coalition, it is common for more than one receiver to require a copy of certain categories of information (for example, General Status Report). In a pure Web service, each of these receivers would have to poll the server at frequent intervals to determine if a new report was available. This makes highly inefficient use of both server processing and network capacity, so C2SIM servers typically implement the Streaming Text Oriented Message Protocol (STOMP) [18], which allows other interested systems to establish a persistent TCP connection and subscribe for various categories ("Topics") of output documents that will be forwarded automatically to subscribing systems over those TCP connections.

As C2SIM is moving towards an operational capability it will be necessary to revisit the standard profiles for core services defined by NATO [19]. The key enabling technologies for a NATO Network Enabled Capability (NNEC) is SOAP Web services while WS-Notification is considered for publish and subscribe of data.

## D. Servers

The primary functions of a typical C2SIM server are [3]:

- Accept push/post C-BML Orders and Reports and MSDL scenario files, in REST format.
- Accept client subscriptions, by Topic (e.g. all General Status Reports).
- Publish the XML documents to subscribers via STOMP as they arrive and be prepared respond to get/pull for them.

A C2SIM server may have other functions:

- Namespaces: XML tagnames can be qualified by addition of a "namespace" code or example <br/>bml:Report> indicates a namespace "bml" is to be used; this allows tagnames from different sources to work together safely without previous disambiguation.
- Schema Validation: the server confirms that each document received conforms to the schema, in order to identify possible incompatibilities. Since this slows the service, normally it is done only during initial testing.
- Filtering Data: the server can restrict delivery, based on user-defined criteria.
- Logging/replay: to achieve this, the server writes a file containing every transaction it receives, with time stamps for each. The server is capable of replaying this file to

recreate the original sequence of Orders and Reports at original time intervals.

- Bridged Servers: multiple servers can be tied together into a distributed server system in order to increase load capacity and increase network efficiency of a C2SIM coalition [20]. Fig. 6 shows a three-server system that was demonstrated in December 2014.
- Aggregating MSDL Inputs from Participating Systems: In a coalition each C2 and simulation system can have different initialization requirements. A consolidated MSDL initialization file is needed for consistency; the server can aggregate them automatically, so that all systems receive common initialization data.
- Schema Translation: A translation capability is needed because developing organizations are reluctant to change their interface each time a new schema is developed, with the result that the coalition finds itself with C2 and simulation systems interfaced to several different (but largely equivalent) schemas. To achieve translation, the server parses the XML document according to appropriate schema, saves the input in an in-memory database, and draws on the database to produce output conforming to different designated schema. (This is possible only where data support the same semantics.) A server with this capability allowed MSG-085 to interoperate C2 and simulation systems that had been interfaced under various previous schemas.



Fig. 6. Three-Server Architecture showing the main flow of information among the participating systems.

#### IV. MAJOR C2SIM EXPERIMENTAL USE TO DATE

Three major, multinational experiments have been conducted and documented. Both MSG-048 and MSG-085 devoted significant effort to experimental configurations. In addition, a French-German coalition focused on logistics was used experimentally [21]. In each case, active and retired military personnel joined the technical development group, with the intention that the SoS would be evaluated in a realistic way.

While it would be possible to use only C2SIM interoperability methods to couple the simulations within a coalition, the primary intention of C2SIM is not simulation-to-simulation; it is sharing information among C2 and simulation systems, and for this the frequency of information update required is on the order of once per minute for most live

military operations except air operations situational awareness information. Experience has shown that simulations can send updates more frequently than most C2 systems are able to accept them. Therefore, in the coalitions reported here, the simulation-to-simulation interconnection was via Distributed Interactive Simulation (DIS) network protocols [22].

#### A. MSG-048 Experimentation

The MSG-048 Technical Activity was chartered to show the technical feasibility of the C2SIM approach. Its efforts culminated in a one-week period of exploratory experimentation, conducted with operational military subject matter experts (SMEs) in 2009. Intensive preparation for this activity took place over the Internet, which at the time was a new way of working for most of the participants. In addition, physical integration events were held in Portsmouth, UK and Paris, France. These events proved to be a successful risk reduction mechanism. The system-of-systems architecture used is shown in Fig. 2. The process followed was basically successful and showed that the technologies used, and the overall BML concept, provide a sound basis for future work. This was confirmed by the participating military, who were not part of the MSG-048 development team and therefore were able to view the results objectively [23]. Evidence that others also were convinced can be seen in the fact that MSG-048 received the NATO Scientific Achievement Award in 2013.

#### B. MSG-085 Final Experimentation

MSG-048 set the stage for MSG-085, which was intended to show the operational military utility of C2SIM. The final demonstration of MSG-085 took place in the US at Fort Leavenworth, Kansas in December, 2013, in partnership with the US Army Mission Command Battle Laboratory. The featured capability was Joint and Combined Mission Planning. The SoS architecture is shown in Fig. 3.

While the complexity of the MSG-048 and MSG-085 final events was roughly similar, there were significant differences in network sophistication, ease of setup, and audience impression [10]. In short, where MSG-048 succeeded in proving the principle that C2SIM technology could be used effectively in coalition operations, MSG-085 succeeded in a harder goal: improving the Technical Readiness Level of C2SIM in the form of MSDL and C-BML while proving the concept that C2SIM is ready to be tested in real coalition operations. The result is reported in [10].

#### C. COMELEC French/German Experiment

This experimentation was performed in December 2011 under the umbrella of the "Commission Electronique et Optronique – sous-comité 9" (COMELEC / SC9) cooperation in Ottobrunn, Germany. The COMELEC C2/Simulation group goal is to promote the common use of national simulations in addressing both interoperability between different simulations and currently between C2 systems and simulations. An expected result is to provide the German-French Brigade with new modeling and simulation capabilities. The activity was focused on enhancing task synchronization, order and report generation, and consistent initialization, using C-BML together with MSDL [21].

#### V. CHALLENGES TO UNDERSTANDING C2SIM AS AN SOS

Reference [24] provides a list of problems frequently encountered in SoS knowledge development. Each of these problems arose in some degree during our work to develop C2SIM.

*Fragmented perspectives*. Our work to date has been very ad-hoc: we find an approach that works and pursue it until/unless it proves unsatisfactory.

Lack of rigorous development and theoretical grounding. As a result, there has been little theoretical exposition regarding design and development alternatives.

Information technology dominance. C2SIM certainly is dominated by information technology, since it addresses interoperation of IT systems. However we can expect this to change in the near future, since the planned operational employment of MSG-145 will involve human commanders and their staffs to a much higher degree than any of our past experiments.

Limitations of traditional System Engineering (SE) single system focus. While it has been clear during development and experimentation with C2SIM that traditional techniques are useful, it also has become clear that there is a "missing science of SoSE" that could illuminate and facilitate such work.

*Whole systems analysis.* That is to say, we lack tools and techniques for analysis of the complex SoS we build as a C2SIM Coalition.

#### VI . CONCLUSIONS AND FUTURE WORK

C2SIM confirms earlier observations about SoS: while it does not have a well-developed theoretical basis and has been developed on a very much ad hoc basis, it has been shown to be remarkably effective in the integration of multiple, dissimilar systems into one large, geographically distributed SoS. We look forward to providing further reports to the SoSE community as C2SIM expands into the domain of real military operations. While that is happening, we also hope to increase our engineering knowledge regarding how a C2SIM Coalition behaves under various input conditions and why it behaves that way.

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