NORTH ATLANTIC TREATY
ORGANIZATION

SCIENCE AND TECHNOLOGY
ORGANIZATION

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STO TECHNICAL REPORT **TR-MSG-145**

Modelling and Simulation Group 145: Operationalization of Standardized C2-Simulation Interoperability

(Groupe de simulation et modélisation 145 :
Mise en service opérationnel du standard
relatif à l'interopérabilité C2-Simulation)

NMSG-145 Final Report.

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- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

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List of Acronyms

AAP	Allied Administrative Publication
ABB	Architecture Building Block
ACO	[NATO] Allied Command Operations
ACT	[NATO] Allied Command Transformation
AJP	Allied Joint Publication
AMSP	[NATO] Allied Modelling and Simulation Standards Profile
AO	Area of Operations
AOX	Air Operations eXtension
APOD	Airport of Debarkation
APP	Allied Procedural Publication
AS	Autonomous System
ASX	Autonomous Systems eXtension
ATEC	[US] Army Test and Evaluation Command
AVT	Applied Vehicle Technology
AWACS	Airborne Early Warning and Control System
BCT	Brigade Combat Team
BML	Battle Management Language
BN	Battalion
C2	Command and Control
C2IS	Command and Control Information System
C2LG	Command and Control Lexical Grammar
C2SIM	C2-to-Simulation
CA^2X^2	Computer Aided Analysis, eXercise, eXperimentation
CAX	Computer Assisted eXercise
C-BML	Coalition Battle Management Language
CCIR	Commander’s Critical Information Requirements
CD&E	[NATO] Concept Development and Experimentation
CEMA	Cyberspace Electro-Magnetic Activities
CFBLNet	Combined Federated Battle Laboratories Network
CGF	Computer Generated Forces
CNAD	[NATO] Conference of National Armament Directors
COA	Course of Action
COP	Common Operational Picture
COPD	[NATO] Comprehensive Operational Planning Directive
CPX	Command Post Exercise
CSE	Common Scenario Editor
CSO	Collaboration Support Office
CWIX	Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise
DAT	Defence Against Terrorism
DCO	Defensive Cyberspace Operations
DDS	Data Distribution Service
DEAD	Destruction of Enemy Air Defences
DGA	[FRA] Direction Générale de l’Armement
DIS	Distributed Interactive Simulation
DMASC	DTEC Modelling and Simulation Standards Profile
DSEEP	Distributed Simulation Engineering and Execution Process

Dstl	[UK] Defence Science and Technology Laboratory
DSET	Defence Simulation Education Training
DTA	[NZL] Defence Technology Agency
DTEC	Defence Training and Education Coherence
ET	Exploratory Team
EW	Electronic Warfare
EXCON	Exercise Controller
FFI	[NOR] Forsvarets forsknings-institutt (Norwegian Defence Research Establishment)
FIPA	Foundation for Intelligent Physical Agents
FLANCON	Flanking Forces Controller
FOB	Forward Operating Base
FOM	Federation Object Model
FTRT	Faster Than Real Time
GBAD	Ground-Based Air Defence
GMU	George Mason University
GO	Government Organization
GPU	Graphics Processing Unit
GSD	Guidelines for Scenario Development
HFM	Human Factors and Medicine
HICON	Higher Forces Controller
HLA	High Level Architecture
HMI	Human-Machine Interface
HTLM5	Hyper-text Mark-up Language 5
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
IADS	Integrated Air Defence System
ICC	Integrated Command and Control
IER	Information Exchange Requirements
IO	International Organization
IST	Information Systems Technology
ITEC	International Training and Education Conference
JC3IEDM	Joint Consultation Command and Control Information Exchange Data Model
JFTC	[NATO] Joint Forces Training Centre
JMP	Joint Mission Planning
JSAF	Joint Semi-Automated Forces
JSON	JavaScript Object Notation
LDM	Logical Data Model
LI	Lessons Identified
LL	Lessons Learned
LLI	Lessons Learned Information
LoA	Level of Autonomy
LOCON	Lower Forces Controller
LOX	Land Operations eXtension
M&S COE	[NATO] Modelling and Simulation Centre of Excellence
MCCIS	Maritime Command and Control Information System
MCIS	Mission Command Information Systems
MDMP	Military Decision Making Process

MGCS	Main Ground Combat System
MIM	MIP Information Model
MIP	Multilateral Interoperability Programme
MS3	[NATO] Modelling and Simulation Standards Subgroup
MSCO	[NATO] Modelling and Simulation Coordination Office
MSDL	Military Scenario Definition Language
MSEL	Master Scenario Events List
MSG	[NATO] Modelling and Simulation Group
NAF	NATO Architectural Framework
NC3A	NATO Consultation, Command and Control Agency
NEC	Network-Enabled Capability
NEO	Non-combatant Evacuation Operation
NETN	NATO Education and Training Network
NFFI	NATO Friendly Forces Information
NGF	New Generation Fighter
NGO	Non-Government Organization
NIAG	NATO Industrial Advisory Group
NISP	NATO Interoperability Standards and Profiles
NMSG	NATO Modelling and Simulation Group
NORCCIS	Norwegian C2IS
NSO	NATO Standardization Office
NURC	NATO Underwater Research Centre
OBW	Operation Blended Warrior
OCEAN	Open Cloud Environment ApplicatioN
OMT	Object Model Template
OneSAF	One Semi-Automated Forces
ORBAT	Order of Battle
OTH-Gold	Over The Horizon – Gold
OWL	Web Ontology Language
PDG	[SISO] Product Development Group
POW	Programme of Work
PPLI	Precise Participant Location and Identification
PSG	[SISO] Product Support Group
QRA	Quick Reaction Alert
R2CD2	Research on Robotics Concept and Capability Development
RA	Reference Architecture
RDF	Resource Description Framework
REST	Representational State Transfer
RPR	Real time Platform Reference
RTA	[NATO] Research and Technology Agency
S&T	Science and Technology
SA	Situational Awareness
SALP	[FRA] Sol-Air à Longue Portée
SAMP	[FRA] Sol-Air à Moyenne Portée
SAS	System Analysis and Studies
SCI	Systems Concepts and Integration
SDA	System Design Agreements
SDEM	Simulation Data Exchange Model

SDF	Standard Development Framework
SET	Sensors and Electronics Technology
SI	Standardization Inquiry
SIE	Single Information Environment
SIMPLE	Standard Interface for Multiple Platform Link Evaluation
SISO	Simulation Interoperability Standards Organization
SIW	SISO Innovation Workshop
SMC	Status Monitoring and Control
SME	Subject Matter Expert
SMX	Standard Military eXtension
SP	Standardization Proposal
ST	Standardization Task
STANAG	[NATO] STANdardization AGreement
STANREC	[NATO] STANdardization RECommendation
STO	[NATO] Science and Technology Organization
STOMP	Simple Text-Oriented Message Protocol
SUS	System[s] Using Simulation
SWAP	Simulation-supported Wargaming for Analysis of Plans
T&E	Test and Evaluation
TA	Technical Activity
TAP	Technical Activity Proposal
TC	Technical Coordinator
TDL	Tactical Data Link
TDSS	Tactical Decision Support System
TG	Technical Group
TIDE	[NATO] Technology for Information, Decision and Execution
TMR	Transfer of Modelling Responsibility
TRL	Technical Readiness Level
TTP	Techniques, Tactics, Procedures
UAV	Unmanned Air Vehicle
UAxS	Unmanned Autonomous System
UGV	Unmanned Ground Vehicle
UP	Urbanisation Project
USG	Use Case Sub Group
VM	Virtual Machine
VMF	Variable Message Format
VPN	Virtual Private Network
W3C	World Wide Web Consortium
WS	Web Services
XML	eXtensible Mark-up Language
XSD	XML Schema Definition
XSLT	eXtensible Stylesheet Language Transformations

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Key Audiences

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5) International C2 and Simulation Interoperability Standards Organizations.	Multilateral Interoperability Programme (MIP) SISO C2SIM Product Development Group

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Modelling and Simulation Group 145: Operationalization of Standardized C2-Simulation Interoperability

(STO-TR-MSG-145)

Executive Summary

This report describes the work and achievements of NATO Modelling and Simulation Group 145 (MSG-145). The group's principal aim has been to provide evidence to support the operationalization of the Simulation Standards Interoperability Organization's (SISO) Command and Control to Simulation (C2SIM) interoperability standard leading to a recommendation that the standard should be proposed for adoption as a NATO Standardization Agreement (STANAG).

The work has built on earlier NATO M&S activities, particularly MSG-048 and MSG-085 which were concerned with the development and use of the Coalition Battle Management Language and the Military Scenario Definition Language (C-BML and MSDL). That work's success encouraged SISO to work on a unified standard, C2SIM, for initialization, tasking/reporting and synchronized operation of the resulting system of systems (which we call a coalition). MSG-145 conducted complementary studies and experimentation to identify, test and demonstrate relevant use cases.

MSG-145's activities covered: the assessment of the draft SISO C2SIM and providing feedback to SISO; developing representative use cases and implementing them in experimental environments; providing a persistent, distributed experimentation/test and evaluation environment, the C2SIM Sandbox; developing an architecture to provide C2SIM as a service and gathering evidence to support the group's proposal to adopt C2SIM as a STANAG.

The assessment of the C2SIM standard package was conducted by examining the underlying data model of C2SIM, as expressed by a set of ontologies, reviewing the documentation and guidance processes.

The use cases led by different national groups covered:

- Unmanned Autonomous Systems (Italy);
- Cyber Warfare in Operational Military Training (USA);
- Mission Planning for Army (Norway);
- Air Operations using Tactical Data Links (France and Germany);
- Joint Mission Planning (United Kingdom); and
- Command Post Training (Germany).

Each of these use cases provided a framework in which to test the C2SIM standard and to help SISO in its work of refining it. The supporting experimentation has been conducted in both national and coalition environments including NATO's Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise (CWIX) and the group's own Mini Exercise (MiniEx). The use cases and experimentation also proved valuable in helping to identify and explore exploitation opportunities. Other work describes a Reference Architecture relevant for systems developers, including those working with M&S as a Service (MSaaS).

Numerous outreach activities have been undertaken: technical papers, presentations, demonstrations and tutorials have all been provided at both home nation and international venues such as: ITEC, I/ITSEC, TIDE Sprint, ICCRTS and the SISO SIW. Full details and references are to be found in the main body of this report.

The group's C2SIM Sandbox is a complete C2SIM environment hosting a representative constructive simulation, a C2 surrogate and a C2SIM web server to provide a network communication capability. Users can connect their own systems using a secure Virtual Private Network (VPN) from anywhere in the world. The Sandbox has been used extensively and a persistent capability is currently hosted at the NATO Modelling and Simulation Centre of Excellence (MSCOE) in Rome.

In conclusion the report summarizes how the group achieved its objectives, identifies exploitation paths and how the C2SIM standard may be used and extended. It also summarizes the outreach activities. Finally, and most importantly for NATO, it covers the recommendation and process required for the adoption of the C2SIM standard by NATO as a STANAG.

The report recommends that:

- A C2SIM STANAG should be proposed and ratified based on SISO C2SIM standard.
- NMSG should promote the C2SIM standard to the nations and industry.
- NMSG should promote the C2SIM standard to NATO Federated Mission Networking (FMN) and add the standard to the NATO Interoperability Standards and Profiles (NISP) and the NATO M&S Standards Profile (STANREC 4815).
- Development of decision support and implementation tools need to be pursued to further develop an operational capability.
- The level of experimentation should be extended to include more use cases to support operational plans.

Groupe de Modélisation et Simulation 145 : Mise en service opérationnel du standard relatif à l'interopérabilité C2-Simulation

(STO-TR-MSG-145)

Synthèse

Ce rapport décrit les travaux et les réalisations du Groupe OTAN relatif à la modélisation et la simulation 145 (MSG-145). Le principal objectif du groupe a été de fournir des preuves à l'appui de l'opérationnalisation de la norme d'interopérabilité Command and Control to Simulation (C2SIM) de l'Organisation de standardisation de l'interopérabilité du domaine de la simulation (SISO), ce qui a conduit à recommander que la norme soit proposée pour adoption en tant qu'accord de normalisation OTAN (STANAG).

Les travaux se sont appuyés sur les activités M&S de l'OTAN antérieures, en particulier MSG-048 et MSG-085 qui visaient le développement et l'utilisation du langage pour la gestion du champ de bataille en coalition et du langage de définition de scénarios militaires (C-BML et MSDL). Le succès de ce travail a encouragé le SISO à travailler sur une norme unifiée, C2SIM, pour l'initialisation, les ordres / rapports et le fonctionnement synchronisé du système de systèmes résultant (ici dénommé une coalition). Le MSG-145 a mené des études et des expérimentations complémentaires pour identifier, tester et démontrer les cas d'utilisation pertinents.

Les activités du MSG-145 couvraient: l'évaluation de la version de travail du standard C2SIM élaborée par le SISO et le partage de commentaires; le développement des cas d'utilisation représentatifs et leurs mises en œuvre dans des environnements expérimentaux; la mise à disposition d'un environnement d'expérimentation / de test et d'évaluation persistant et distribué, le Sandbox C2SIM; la définition d'une architecture pour inclure C2SIM en tant que service et rassembler des preuves pour appuyer la proposition du groupe d'adopter C2SIM en tant que STANAG.

L'évaluation de la globalité du standard C2SIM a été réalisée en examinant le modèle de données sous-jacent du C2SIM, exprimé sous la forme d'ontologies, et la documentation et les processus de mis en œuvre.

Les différents groupes nationaux se sont attachés aux cas d'utilisation suivants :

- Systèmes autonomes sans pilote (Italie) ;
- Menace Cyber pour l'entraînement opérationnel (États-Unis) ;
- Planification de missions pour l'armée de terre (Norvège) ;
- Opérations aériennes utilisant des liaisons de données tactiques (France et Allemagne) ;
- Planification de missions interarmées (Royaume-Uni) ; et
- Entraînement des postes de commandement (Allemagne).

Chacun de ces cas d’utilisation a fourni un cadre dans lequel tester la norme C2SIM et aider le SISO dans son travail de perfectionnement de la norme. En appui, des expérimentations ont été menées à la fois dans des environnements nationaux et en coalition, notamment lors du Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise (CWIX) et lors du Mini Exercice (MiniEx) du groupe. Les cas d’utilisation et les expérimentations se sont également révélés utiles pour aider à identifier et à explorer les opportunités d’emploi. D’autres travaux ont permis de définir une architecture de référence appropriée pour les développeurs de systèmes, y compris ceux en charge d’implémenter la simulation en tant que services (MSaaS).

De nombreuses activités de vulgarisation ont été entreprises: des publications techniques, des présentations, des démonstrations et des tutoriels ont tous été partagés à la fois au plan national et lors d’évènements internationaux tels que: ITEC, I / ITSEC, TIDE Sprint, ICCRTS et SISO SIW. Tous les détails et les références sont consultables dans le présent rapport.

Le bac à sable C2SIM autrement appelé C2SIM Sandbox réalisé et distribué par le groupe comprend un environnement C2SIM complet. Il héberge une simulation constructive représentative, un substitut de système C2 et un serveur Web C2SIM fournissant les services de communication réseau. Les utilisateurs peuvent connecter leurs propres systèmes à l’aide d’un réseau privé virtuel (VPN) sécurisé de n’importe où dans le monde. Le bac à sable a été largement utilisé et une capacité pérenne est actuellement hébergée au Centre d’excellence OTAN de modélisation et de simulation (MSCOE) à Rome.

En conclusion, le rapport résume comment le groupe a atteint ses objectifs. Il identifie les cas d’emploi et comment la norme C2SIM peut être utilisée et étendue. Il résume également les activités de vulgarisation. Enfin, et surtout pour l’OTAN, il recommande l’adoption de la norme C2SIM par l’OTAN en tant que STANAG et ouvre la voie pour débuter le processus de ratification.

En synthèse, le rapport propose les recommandations suivantes:

- Un STANAG C2SIM devrait être proposé et ratifié sur la base de la norme SISO C2SIM.
- Le NMSG devrait promouvoir la norme C2SIM auprès des nations et de l’industrie.
- Le NMSG devrait promouvoir la norme C2SIM dans le cadre du projet OTAN Federated Mission Networking (FMN) et l’ajouter aux normes et profils d’interopérabilité de l’OTAN (NISP) et au profil des normes M&S de l’OTAN (STANREC 4815).
- Le développement d’outils d’aide à la décision et de mise en œuvre de la norme C2SIM devrait être poursuivi pour développer davantage la capacité opérationnelle.
- Le volume d’expérimentations devrait être étendu pour inclure davantage de cas d’utilisation illustrant les besoins opérationnels.

Chapter 1 – INTRODUCTION

This is the final report of the MSG-145 Technical Activity (TA), *Operationalization of Standardized C2-Simulation Interoperability*. Its intended audience is the NATO technical community, in particular, those working in the domains of Command and Control (C2) and Modelling and Simulation (M&S).

This document describes the work and findings of the MSG-145 TA that is a follow-on activity to MSG-085. The background for MSG-085 is largely documented in the final report [1].

1.1 DOCUMENT OVERVIEW

This report is structured as follows:

- Introduction (Chapter 1);
- MSG-145 Overview (Chapter 2);
- C2-Simulation Operationalization Tasks (Chapter 3);
- Experiments, Workshops and Conferences (Chapter 4);
- Lessons Identified and Lessons Learned (Chapter 5);
- Future Exploitation (Chapter 6);
- Conclusions and Recommendations (Chapter 7); and
- References and Bibliography (Chapter 8).

Annexes cover:

- C2SIM Reference Architecture (Annex A);
- 2019 Mini Exercise (Annex B);
- 2019 Air Operation Extension Demonstration (Annex C); and
- The proposal to adopt the SISO C2SIM standard as a NATO STANAG (Annex D).

1.2 WHY STANDARDIZE C2SIM INTEROPERABILITY?

Interoperation among C2 and simulation systems is a common and significant theme in the transformation of modern military forces. It is required to support the military enterprise in the execution of business activities and mission threads such as operational training, information sharing and decision support. This requirement implies the ability to seamlessly integrate C2 systems and simulation systems and to provide the means for a meaningful and unambiguous information exchange. C2SIM interoperation applies to systems of systems functioning toward a common goal at different levels:

1) Within services;
2) Across services (i.e., joint); and
3) Across nations in a multinational or coalition context.

Furthermore, the advent of autonomous Unmanned Vehicle Systems (UVS) has led to requirements for increased interoperation among C2 systems and the emerging category of robotic forces. The increasing employment of Unmanned Systems creates the need to develop and validate new concepts of operation and therefore the need for experimentation capabilities. The requirements for communication between C2 systems and robotic systems are similar in many ways to those for communication between C2 systems and simulation systems.

In such a "systems of systems" environment, the control of one system by another requires an unambiguous, automated mechanism wherein C2 and M&S concepts can be linked in an effective and open manner.

Interoperation among C2 and simulation systems is required to support military activities such as: Force Readiness; Support to Operations; and Capabilities Development. Currently, interoperating systems from different manufacturers and/or nations requires proprietary interfaces that require time and money to develop and maintain. Furthermore, in many cases, in addition to these vendor-specific interfaces, human intervention is required during military scenario definition, initialization and execution. The so-called "swivel-chair" interface entails feeding simulation operators with information that they must translate manually into instructions that the simulations can process. Replacing such operators with a standardized, automated interface can save considerable expense and at the same time result in more robust and timely operations.

Developing standards that define common interfaces for the exchange of military information among C2 and simulation systems therefore can lead to significant cost-reduction and greatly facilitate systems integration.

The benefits of standardizing C2SIM interoperation include: reduced cost and workload; reduced scenario preparation time; and increased realism and overall effectiveness.

1.3 C2SIM INTEROPERABILITY STANDARDS

Stakeholders have recognized the importance of establishing an internationally accepted standard that provides for a system-independent language and protocols.

1.3.1 C-BML

Battle Management Language (BML) is an unambiguous language used to command and control forces and systems conducting military operations. BML is being developed as a standard representation and means for communicating digitized C2 information such as orders and plans to be understandable for military personnel, for simulated forces, and for future robotic forces. In addition, BML must provide for situational awareness and a shared, Common Operational Picture (COP) through digitized reports. BML is particularly relevant in a network centric environment for enabling mutual understanding. BML also must facilitate C2SIM interoperability in an environment where multinational distributed integrated capabilities are becoming more common and important.

BML is independent of doctrine but provides a means for expressing doctrine. However, BML is not intended as a means to standardize doctrine: the vocabulary must be well defined in the context of the respective application domain to unambiguously generate executable tasks at the end of the process. BML must model these aspects in a way that underlying Information Technology systems (M&S or C2 systems) can exchange information and also can properly interpret the results. Therefore, the Simulation Interoperability Standards Organization (SISO) undertook the development of standard for BML, the Coalition Battle Management

Language (C-BML) that uses data definitions from the JC3IEDM. The Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM) was selected since it represents an accepted and well-defined set of information elements. However, the JC3IEDM message structure is not part of the C-BML standard.

In April 2014, SISO approved the initial version of C-BML, a standardized formal language for the exchange of digitized military information among Command and Control (C2), simulation and autonomous systems. C-BML is an interoperability standard that can greatly facilitate the preparation and execution of military scenarios in support of military enterprise activities.

1.3.2 MSDL

Use-case scenarios involving information exchange among C2 systems and simulation systems often require a pre-requisite initialization of all systems that is consistent with existing operational and/or simulation databases.

The Military Scenario Definition Language is intended to reduce scenario development time and cost by enabling creation of a separable simulation independent military scenario format, focusing on real-world military scenario aspects, using the industry standard data model definition XML that can easily and dependably be consumed by current and evolving simulations. The initial MSDL capability was prototyped within the US Army's One Semi-Automated Forces (OneSAF) program during its early architectural development phase between 2001 and 2004. A SISO Study Group (SG) concluded that there was a community-wide need for a standardized military scenario format to reduce development time and cost, and to enable sharing of valuable scenario products. The standardized scenario format also provides a way to automate the largely manual reproduction of a scenario into multiple simulation scenario formats and reduce the number of errors introduced during this manual process.

In 2006, a formal SISO MSDL standard Product Development Group (PDG) was established with the specific intent of producing a standard Military Scenario Definition Language data model. The PDG reviewed previous OneSAF work, expanded and aligned it with the JC3IEDM. Version 1.0 of the resulting SISO standard was approved in November 2008. Beyond OneSAF, MSDL has been employed by the US Army Modeling and Simulation Office (AMSO), Air Force, and Marine Corps as well as NATO activities.

1.3.3 C2SIM

The MSDL and C-BML standards, developed by SISO to respectively support scenario initialization and scenario execution, are currently harmonized to establish a combined C-BML/MSDL standard also called C2SIM standard. Toward that end, in 2014 SISO merged the C-BML and MSDL Product Development Groups (PDGs) to form the C2SIM PDG. This has resulted in a second-generation, harmonized standard which keeps the benefits of C-BML and MSDL and also provides extensibility.

Figure 1-1 shows the operating concept, C2SIM enables the exchange of messages (e.g., plans, orders and reports) and initialization data between C2 systems, M&S applications and autonomous systems.

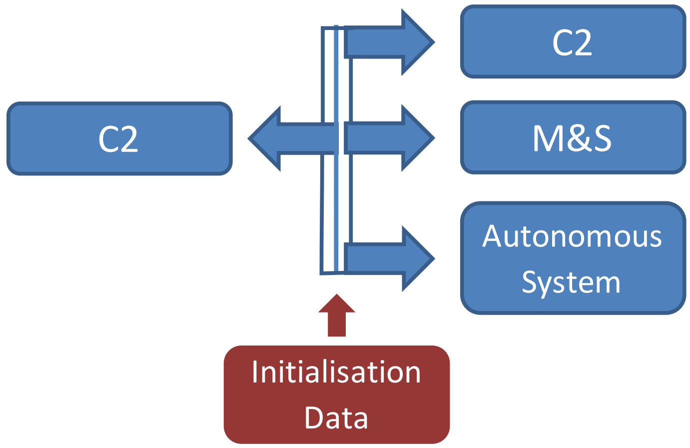

Figure 1-1: C2SIM Concept Overview.

1.4 PREVIOUS WORK BY NATO ON STANDARDIZATION FOR C2SIM INTEROPERATION

The Modelling and Simulation Group (MSG) of the NATO Coordination Support Office (CSO) has supported several technical activities related to C2SIM interoperation in recent years. MSG-145 is a follow-up activity to the MSG-085 and MSG-048 technical activities that were conducted from 2006 to 2014. The NATO Exploratory Team-038 (ET-038) was held in September 2015, prior to the start of MSG-145 in March 2016.

The feasibility of C2SIM was demonstrated by MSG-048 and the utility of C2SIM interoperability has been demonstrated by MSG-085. MSG-145 intends to operationalize C2SIM.

1.4.1 NATO MSG-048

The MSG-048 Technical Activity explored the technical feasibility of a "Battle Management Language" (BML) as a component of an open framework to link C2 systems and M&S or robotic systems in the NATO context.

The findings of MSG-048 provided a set of lessons learned, rich in experience from the MSG-048 experimentation program. A set of operational and technical requirements for C2SIM interoperation has proven usefulness for the Simulation Interoperability Standards Organization (SISO) C-BML standardization activities as well as informing the MSG-085 Technical Activity. In 2013, MSG-048 received the NATO Scientific Achievement Award for this work.

1.4.2 NATO MSG-085

The results of the follow-on activity to MSG-048, the MSG-085 TA initiated in 2010, and thanks largely to significant involvement from the operational community, have established a clearer scope and refined set of operational and technical requirements for C2SIM interoperability. The proof of concept has been demonstrated by MSG-085 through several experimentation events. They first confirmed the operational relevance and measured the benefits of existing C2SIM interoperability approaches. They also identified limitations and areas of improvements of existing technologies and helped to inform the broader community concerning the state-of-the-art in C2SIM interoperability. The most important of all, the lessons learned from these events contribute to the elaboration of a set of recommendations for the SISO standardization body that is developing C2SIM interoperability standards. One main recommendation was that C-BML and MSDL should be based on a common data model and merged into one C2SIM standard.

1.4.3 NATO ET-038

The scope of the exploratory team, stated in 2015, was to explore and define the future technical works NATO needs to execute in order to operationalize C2SIM interoperability. In fact, there is much technical effort remaining to improve C2SIM. Both MSDL and C-BML need to have a next generation developed to facilitate both their working together and the scope of the interoperability they are able to achieve. MSDL should meet the needs of a wide range of national and NATO systems, while C-BML should improve both the sophistication of what it can represent and ease of using it to represent sophisticated situations. The consensus among stakeholders to merge these two activities to generate a unified, more manageable and easier to deploy C2SIM interoperability solution was analyzed to scope future TA. It gave birth to MSG-145.

Chapter 2 – MSG-145 OVERVIEW

The MSG-145 Mission Statement is as follows:

> *Assess the C2SIM standard in development and implement extensions to the unified C2SIM Logical Data Model[1] (LDM) for specific functional areas in order to demonstrate its usability to the simulation community and support the definition of a STANAG.*

2.1 BACKGROUND

The MSG-145 Technical Activity builds upon the work done in MSG-048 and MSG-085. The focus of MSG-085 was on demonstrating the proof of concept of a C-BML/MSDL enabled approach to C2SIM interoperation while MSG-048 focus was to assess the technical relevance of C-BML. The MSG-085 TA addressed the problem areas and obstacles highlighted in MSG-048 and provided guidance and input to in support of the finalization of the C-BML standard and its alignment with MSDL. In addition, MSG-085 sought to ensure that the second-generation standard supports the operational use cases as collected from the nations and NATO stakeholders. This allows for C2SIM interoperation while providing feedback to the community for initiatives that will ultimately result in an increase in the Technical Readiness Level (TRL) of C-BML-related technologies to a level consistent with operational employment.

Although the final goal of the MSG-085 TA does not lie solely in the adoption of a single standard or technology, the participating nations have identified building upon C-BML and MSDL as the key enabling technologies for unified, extensible C2SIM interoperation.

2.2 OBJECTIVES

The MSG-145 high-level objectives are described below. These objectives are taken largely from the MSG-145 TAP [2]. They are subsequently broken down into a set of activities to which items of work are attributed. The principal high-level objectives of the MSG-145 are as follows:

- Exploit C2SIM with use cases through an operational, conceptual and executable scenario development process by engaging the operational community;
- Develop required extensions to the C2SIM Logical Data Model Core for specific functional areas;
- Inform the standards development process and motivate suppliers to develop products;
- Educate the community of practice on C2SIM technology employment and encourage nations to use the standards; and
- Make recommendations for "covering" the C2SIM standard with a STANAG.

[1] The C2SIM Logical Data Model (LDM) will provide, at a logical level (i.e., independent of how the data will be communicated), a Core set of data elements common to most C2 and Simulation systems, combined with a standard way of adding to that Core a collection of additional elements specific to a particular domain and/or context. The LDM captures the essential elements for C2SIM use and operation in the form of classes, attributes and relationships in an ontology. The data model can be transformed into an XML schema for interoperating systems to create and exchange XML documents.

2.2.1 Exploit C2SIM with Use Cases Through an Operational, Conceptual and Executable Scenario Development Process by Engaging the Operational Community

A primary objective of MSG-145 is to exploit C2SIM by providing use cases. These use cases are captured and expressed with scenario following definitions proposed by the SISO Guideline on Scenario Development (GSD) Product Development Group (PDG) [3]. Operational scenarios are used to define and model operational needs. Conceptual scenarios represent re-usable abstractions of scenario and therefore are made independent of any concrete elements such as theatre of operation. The executable scenario represents executable versions of the scenario and are directly usable for experimentation. It is expressed in C2SIM language.

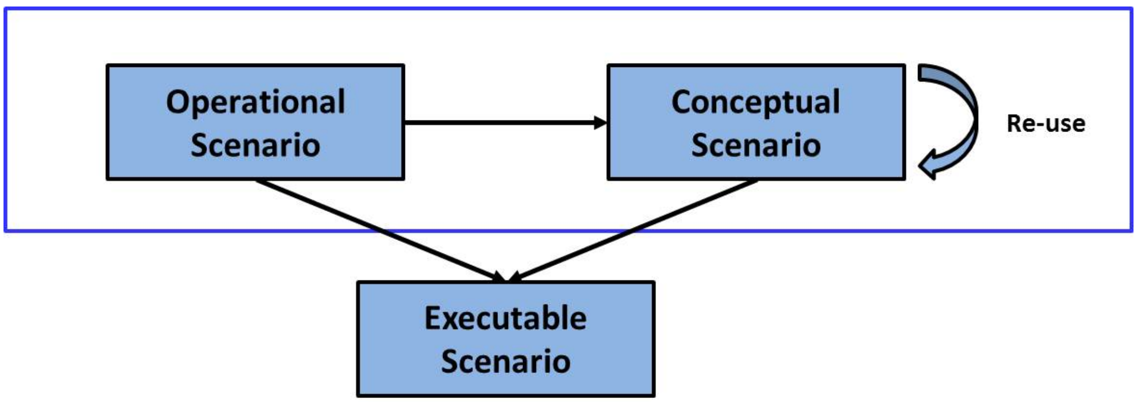

Figure 2-1: Scenario Process.

The NATO Architectural Framework (NAF) was used to understand and to model the user requirements and various types of scenarios required by C2SIM interoperability.

2.2.2 Develop Extensions to the C2SIM Logical Data Model Core for Specific Functional Areas

The second objective is to identify and develop extensions to the C2SIM Logical Data Model for specific functional areas such as autonomous systems or air operations using Tactical Data Links (TDL). Those extensions were developed according to the process defined in the C2SIM standard. The development of those extensions provided feedback to the SISO PDG and contributed to the assessment of the standard.

2.2.3 Inform the Standards Development Process and Motivate Suppliers to Develop Products

The third objective is to promote the C2SIM standard and to motivate suppliers to integrate the standard in their products. This was achieved through the following objectives:

- Informing the supplier base and military operations community on the status and usefulness of C2SIM;
- Facilitating the standardization of C2SIM by providing recommendations to the standardization bodies;
- Promoting the maturity of C2SIM technology toward a level consistent with operational employment; and
- Assisting the community with the future adoption of C2SIM.

The recommendations made are based on experimentation and development of experimental extensions to C2SIM LDM ontology. These and other findings are made available for general dissemination to the public for educational purposes.

Achieving these objectives required close interaction with the SISO C2SIM PDG.

2.2.4 Educate the Community of Practice on C2SIM Technology Employment and Encourage Nations to Use the Standards

The C2SIM technology was disseminated in the form of workshops, lecture series, presentations of technical activities and experimentation during simulation events such as International Training and Education Conference (ITEC), Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), the NATO Computer Aided Analysis, eXercise, eXperimentation (CA^2X^2) (formerly CAX) Forum and the International Command and Control Research and Technology Symposium (ICCRTS).

2.2.5 Make Recommendations for "Covering" the C2SIM Standard with a STANAG

The process to reach STANAG ratification was started in order to support adoption of the C2SIM standard by the NATO body.

2.3 ACTIVITIES

Toward the attainment of the above-stated objectives, the MSG-145 TA performed the following activities:

1) Assess the draft C2SIM Standard;
2) Gather lessons learned from C2SIM assessment;
3) Apply (implement) the standard according to use cases and conduct experiments;
4) Gather lessons learned to develop best practices to implement C2SIM;
5) Provide a distributed environment for test, evaluation and experimentation;
6) Execute operational demonstration to conclude TG activity;
7) Develop C2SIM as a Service approach;
8) Gather evidence from each of the nations for STANAG validation;
9) Technical activity management; and
10) Outreach to the community.

The following sections provide an overview of the activities comprising the MSG-145 TA, how these activities were coordinated over time in a series of phases and how these activities contributed to the objectives stated in the previous section.

2.3.1 Assess the Draft C2SIM Standard

To support the work of the SISO C2SIM PDG, the MSG-145 have assessed the draft C2SIM standard by reviewing the usability of the Core and Standard Military Extension ontologies and its current extensions such as the *Land Operations eXtension* (LOX). The process of extending the core LDM was assessed to check the effectiveness and completeness of documentation and procedures described by the draft standard. This assessment was performed by the experts of the MSG-145 participants, including the effectiveness of the combination of initialization and tasking/reporting.

The SISO C2SIM PDG Core LDM extension process is based on standards and guidance documentation and tool usage (such as Protégé [4] an open source ontology editor and framework for building intelligent systems) to support the definition of extensions. The MSG-145 participants evaluated the potential tools, the description of their use and also the Foundation for Intelligent Physical Agents (FIPA) model that provides effective communication following a reliable model where needed [5].

2.3.2 Gather Lessons Identified from C2SIM Assessment

The lessons identified during the draft C2SIM standard assessment were gathered in a C2SIM assessment report. This report provided recommendations to improve the current standard and was distributed to the SISO C2SIM PDG.

2.3.3 Apply (Implement) the Standard According to Use Cases and Conduct Experiments

The C2SIM standard was implemented and extended for a number of use cases proposed by nations:

- Unmanned Autonomous Systems (Italy);
- Cyber Warfare in Operational Military Training (USA);
- Mission Planning for Army (Norway);
- Air Operations using Tactical Data Links (France and Germany);
- Joint Mission Planning (United Kingdom); and
- Command Post Training (Germany).

In addition, the USA has assembled a “C2SIM Sandbox” operated by the George Mason University (GMU) C4I and Cyber Center that provided a continually available capability to demonstrate and test components and full systems for C2SIM coalitions:

- Using the complete system of C2, server, and simulation;
- Sending orders to the server and getting back reports to be displayed; and
- By issuing orders within the Sandbox that pass through the Sandbox server and go to the simulation being tested.

As well as national assessments and experimentation, much of the group’s testing of the standard was conducted in a set of coalition experiments based on a realistic operational scenario, this was the MSG-145 MiniEx.

2.3.4 Gather Lessons Identified to Develop Best Practices to Implement C2SIM

The lessons identified during the use case experiments are presented in Chapter 5.

2.3.5 Provide a Distributed Environment for Test, Evaluation and Experimentation

In support of MSG-145, a “sandbox” testbed for C2SIM was developed and remotely operated by the GMU C4I and Cyber Center. This was a continually available environment, available by VPN to national teams to demonstrate C2SIM and also for testing/validation of C2 and simulation systems implementing C-BML, MSDL, and also the new C2SIM standard including implementation of *Land Operations eXtension* (LOX). In addition to these functions, the C2SIM Sandbox has built experience toward a future C2SIM as a Service capability. Financial support for student efforts at GMU was provided by the NATO Collaboration Support Office (CSO). The C2SIM Sandbox has been transitioned to the NATO Modelling and Simulation Centre of Excellence (M&S COE) for continued use.

The C2SIM Sandbox employed a surrogate C2 system (the C2SIMGUI open source C2SIM editor from GMU C4I and Cyber Center) and a commercial combat simulation (VT MÄK VR-Forces), along with the open source Reference Implementation C2SIM Server from GMU C4I and Cyber Center, operating in a virtual computing environment. Initially the Sandbox was supporting the four MSG-085 schemas. Under MSG-145, it added support for the new C2SIM Core with Standard Military Extension (SMX) and LOX with capabilities equivalent to existing MSG-085 MSDL Scenario Files and C-BML Orders and Reports. In addition, the Sandbox was improved to support the autonomous system use case extension in a collaboration between the GMU C4I and Cyber Center and the M&S COE.

2.3.6 Execute Operational Demonstrations and Testing to Conclude TG Activity

Operational demonstrations to showcase selected use cases were organized during major simulation and C2 events (such as I/ITSEC, ITEC, CA^2X^2 Forum and ICCRTS) or exercises and testing (such as Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise (CWIX) held at the NATO Joint Forces Training Centre (JFTC) at Bydgoszcz, Poland).

Dedicated liaison with NATO Allied Command Transformation (ACT), NATO Joint Warfare Centre (JWC) and national warfare centers took place in order to prepare for operational demonstrations.

2.3.7 Develop C2SIM as a Service Approach

Drawing on the work of MSG-164 (Modelling and Simulation as a Service (MSaaS) Phase 2)) the group developed a service-based reference architecture specification. This is described in detail in Annex A. Additionally, the implementation of the C2SIM Sandbox and various national C2SIM implementations have used service-based software architectures.

2.3.8 Gather Evidence from Each of the Nations for STANAG Validation

This activity focused on collecting evidence from each of the participating nations about the benefits of adopting a STANAG on C2SIM standard. A proposal was written to initiate the process for production of a C2SIM STANAG. However, it is beyond the group’s remit to execute the STANAG process.

2.3.9 Technical Activity Management

This activity entails communication with the NMSG and Modelling and Simulation Coordination Office (MSCO) including coordinating the preparation of the following documents:

1) Bi-annual briefing during the NMSG Business Meeting;
2) Annual progress report; and
3) The TA final report.

This activity also involves coordination with the Collaboration Support Office (CSO) concerning requests for the support in the framework of the CSO Consultant and Exchange Program and Cooperative Planning Program.

2.3.10 Outreach to the Community

In order to outreach the operational stakeholder and the C2 and simulation community, MSG-145 ensured that the result of the technical activity were reported in various conference and workshop proceedings dealing with C2 and simulation interoperability and autonomous systems such as the ICCRTS, SISO Simulation Innovation Workshop (SIW), I/ITSEC, ITEC, CA^2X^2 Forum, NMSG Symposium, NATO Technology for Information, Decision and Execution (TIDE) Sprint, and related national events.

2.4 MSG-145 ORGANIZATION

In order to efficiently conduct the above-mentioned activities, the MSG-145 TA was organized as below:

- The MSG-145 Group formed by the MSG-145 National Leads;
- The Use Case Sub Groups (USGs) – one sub group per use case; and
- The Technical Coordinator (TC).

The USGs are in charge of conducting experiments and reporting including the definition for their respective use case.

The TC is in charge of producing the technical C2SIM standard assessment to the C2SIM SISO PDG.

2.4.1 Phases

The activity was broken down over four phases as described in Table 2-1:

- Phase 1: Development of the Program Of Work (POW) activity;
- Phase 2: C2SIM assessment, use case analysis, and extensions development;
- Phase 3: Experiments to evaluate, and demonstrations to showcase, use cases; and
- Phase 4: Recommendation for STANAG.

The first phase entailed the elaboration and approval of the Program of Work by all of the nations.

The second phase corresponded to the technical assessment of the C2SIM standard and in particular the assessment of the Logical Data Model. Extensions to the LDM were also addressed during this phase.

The third phase consisted of evaluating the C2SIM standard and extensions through organization of experimentations and promote the standard by organizing demonstrations.

During the fourth phase a STANAG was proposed for C2SIM standard.

Furthermore, the “Communication, Workshops and Symposia” activity were conducted in parallel to all the phases of the project.

Table 2-1: MSG-145 Phases Overview.

<table>
<tr><th></th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th></tr>
<tr><td>Phase 1</td><td>POW Development</td><td colspan="4"></td></tr>
<tr><td rowspan="4">Phase 2</td><td></td><td colspan="3">Standard Assessment</td><td></td></tr>
<tr><td></td><td colspan="2">Use Case Requirements</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="4">C2SIM Extension Development</td></tr>
<tr><td colspan="2"></td><td colspan="3">Review STANAG Process</td></tr>
<tr><td>Phase 3</td><td></td><td>Identify Target Events</td><td colspan="2">Conduct Experiment and Demonstration</td><td></td></tr>
<tr><td rowspan="3">Phase 4</td><td colspan="3"></td><td colspan="2">Final Report Development</td></tr>
<tr><td colspan="3"></td><td colspan="2">STANAG Definition support</td></tr>
<tr><td></td><td colspan="4">Communication, Workshops and Symposia</td></tr>
</table>

Table 2-2 represents the mapping between the technical activities and the phases of MSG-145.

Table 2-2: MSG-145 Technical Activities and Related Phases.

Activity	Phase 1	Phase 2	Phase 3	Phase 4	Communication, Workshops and Symposia
Assess the draft C2SIM standard.		X			
Gather lessons identified from the C2SIM assessment.		X			
Apply (implement) the standard according to use cases and conduct experiments.		X	X		
Gather lessons identified to develop best practices to implement C2SIM.		X	X		
Provide a distributed environment for test, evaluation and experimentation.		X	X		X
Execute operational demonstration to conclude TG activity.			X		X
Develop C2SIM as a service approach.		X	X		

Activity	Phase 1	Phase 2	Phase 3	Phase 4	Communication, Workshops and Symposia
Gather evidence from each of the nations for STANAG validation.			X	X	
Technical Activity management.	X	X	X	X	X
Outreach to the community.					X

2.4.2 Deliverables

The MSG-145 Technical Activity has produced the following set of deliverables:

1) The current MSG-145 Technical Activity Final Report, including recommendations for the implementation of C2SIM interoperability standard;
2) The C2SIM reference architecture document, providing guidelines to design C2SIM environment, is provided as Annex A to this document; and
3) A proposed set of C2SIM extensions to complement the C2SIM standard with examples in applying it (e.g., Air Operation Extension). Available on the SISO Digital Library [6].

Chapter 3 – C2SIM OPERATIONALIZATION TASKS

One of the main objectives of the MSG-145 Technical Activity was to establish a set of operational situations to experiment in real conditions the C2SIM Standard. This chapter describes the work that was conducted toward this objective.

3.1 USE CASE DESCRIPTION AND IMPLEMENTATION

3.1.1 Unmanned Autonomous Systems (Italy)

3.1.1.1 Objectives

The Autonomous System (AS) use case was developed by the Modelling and Simulation Center of Excellence (M&S COE) in the framework of the "Research on Robotics Concept and Capability Development (R2CD2)" project, whose aim was to leverage M&S technology in order to perform Concept Development and Experimentation (CD&E) activity on Unmanned Autonomous Systems (UAxS) employment in the modern urban battlefield. The project was designed to support the NATO Transformation with reference to new Autonomous Systems capability for employment and countering robotic systems. The M&S COE level of ambition is to investigate on five main areas relative to near or mid-term future employment of UAxS in urban environment:

- Interaction between human troops and robots – military C2 of robotic units;
- Verification and Validation (V&V) of AS;
- Technical Tactical Procedures (TTPs) for UAxS;
- Development of functional requirements of new robotic platforms; and
- Countering UAxS.

The R2CD2 project during the period of MSG-145 concentrated into some of these points, dealing with: the interaction between simulated UAxS and real C2 Systems; study of UAxS employment in a megacity of the future (for land and air domains); decision-making support for UAxS – implemented either on an external system or directly on simulated UAxS based on their level of autonomy. In order to perform experimentation about new UAxS-related concepts and standards, with these objectives in mind, a prototype of a scalable and modular demonstrator, based on open standards and selected constructive simulators, was built during the R2CD2 project in collaboration with the industry and academia. Thanks to the ability that M&S technology gives to reuse models, proof of concept prototypes, systems, studies, saving precious resources, for this demonstrator the followings elements have been re-used: the Level of Autonomy (LoA), concept developed during the Autonomous Systems Countermeasures (C-UAxS) project of the ACT, for the robotic behavior and degree of human-robot interaction; Archaria urban model, a model of a mega city of the future built during the ACT Urbanization Project (UP) by the NATO M&S COE, for the terrain generation. The LoA concept deserves a brief description and some definitions since it is of central importance for the requirements of the C2 messages exchange and of the demonstrator architecture. Conceptually, these LoAs are more based on the mission and the human-machine interaction than on the real skills/features which technology enables to machines. In the R2CD2 project the LoAs was grouped into three categories to simplify the UAxS modelling: LOW, MEDIUM and HIGH:

- **LOW** – Humans only gather, monitor and analyze data, make decision, while UAxS do not assist. Neither collision avoidance nor environment recognition are implemented in the UAxS behavior, so they need well defined routes from an external system.
- **MEDIUM** – UAxS gather, monitor, analyze data, but humans interpret them. UAxS assist in ranking task, but humans can veto machine actions and decisions. UAxS have good navigation skills in the environment and collision avoidance is implemented, so few waypoints are necessary in the order.
- **HIGH** – UAxS perform a mission gathering, monitoring and analyzing data; humans are informed only at the end of the mission. UAxS have excellent navigation skills in the environment and collision avoidance is implemented. Only final destination is communicated to the UAxS in the order and they decide all.

Linked to LoA is the idea that autonomous functions, which allow to perform a task autonomously, can be separated from platforms. Basically, an Autonomous System (AS) can have autonomous functions and/or automated function (with pre-determined output) as well as a manned system can be characterized by manned, automated and/or autonomous function. According to the LoA of the AS, autonomous functions should be assured either by the autonomous platforms or external subsystems. For example, in the R2CD2 project, for low LoAs, Autonomy Functions for mission planning are taken over by an external tool, in order to find the best paths for reconnaissance and exfiltration missions, based on information about the terrain and enemy. For this reason, a decision-making tool was paired with the C2 System in order to generate orders to simulated UAxS

The UAxS work contributed to assess the usability of the SISO C2SIM Standard by identifying possible improvements in the extension mechanism according to the Core Logical Data Model concept. The use case explored the requirements for commanding different kinds of simulated and real autonomous systems. During this work, feedback was provided to the SISO PDG about the mechanism for extension development and its documentation.

3.1.1.2 Implementation/Architecture

The methodology/process followed to develop the Autonomous System Extension (ASX), and consequently to define the architecture of the R2CD2 project demonstrator, was the standard process described in Section 3.5. The first step is to search for requirements of the message exchange, the Information Exchange Requirements (IER), using a scenario-based methodology delineated in the SISO Guidelines for Scenario Development (GSD). The IERs are the main source for requirements of new data classes necessary for orders, reports and initialization information to build the ASX. Once the IERs are defined, the ASX can be developed.

The second step was to build an ontology for the C2SIM extension to ASX, i.e., the necessary vocabulary and semantics needed to extend the core of the language to add information to messages, suitable for missions of UAxS according to operational IERs. Finally, the C2SIM eXtensible Markup Language (XML) schema of ASX can be obtained applying an eXtensible Stylesheet Language Transformation (XSLT), according to the rules fixed by SISO C2SIM PDG. The XML schema is essential to build orders, reports and initialization files to execute the scenario, and to develop the software for the C2SIM interfaces of all simulators and other elements of the R2CD2 project demonstrator. The resulting architecture of the R2CD2 prototype (Figure 3-1) is composed of:

- C2SIMGUI of the George Mason University (GMU) as open source C2SIM order editor and displayer of reports;
- Open source C2SIM Reference Implementation Server, developed by GMU and customized for handling the ASX schema;

- VT MÄK VR-Forces as simulator of air domain;
- MASA Sword as simulator of land domain;
- C2SIM interface for VR-Forces simulator for handling the ASX schema to generate tasks of entities and producing position and observation reports; and
- C2SIM interface for Sword simulator for handling the ASX schema to generate tasks of entities and producing position and observation reports.

Tactical Decision Support System (TDSS) of the University of Defence in Brno (CZE) as external software for decision-making support, fully supporting the C2SIM ASX to enrich orders with detailed paths to follow for missions to low LoA UAxS and to read reports produced by UAxS.

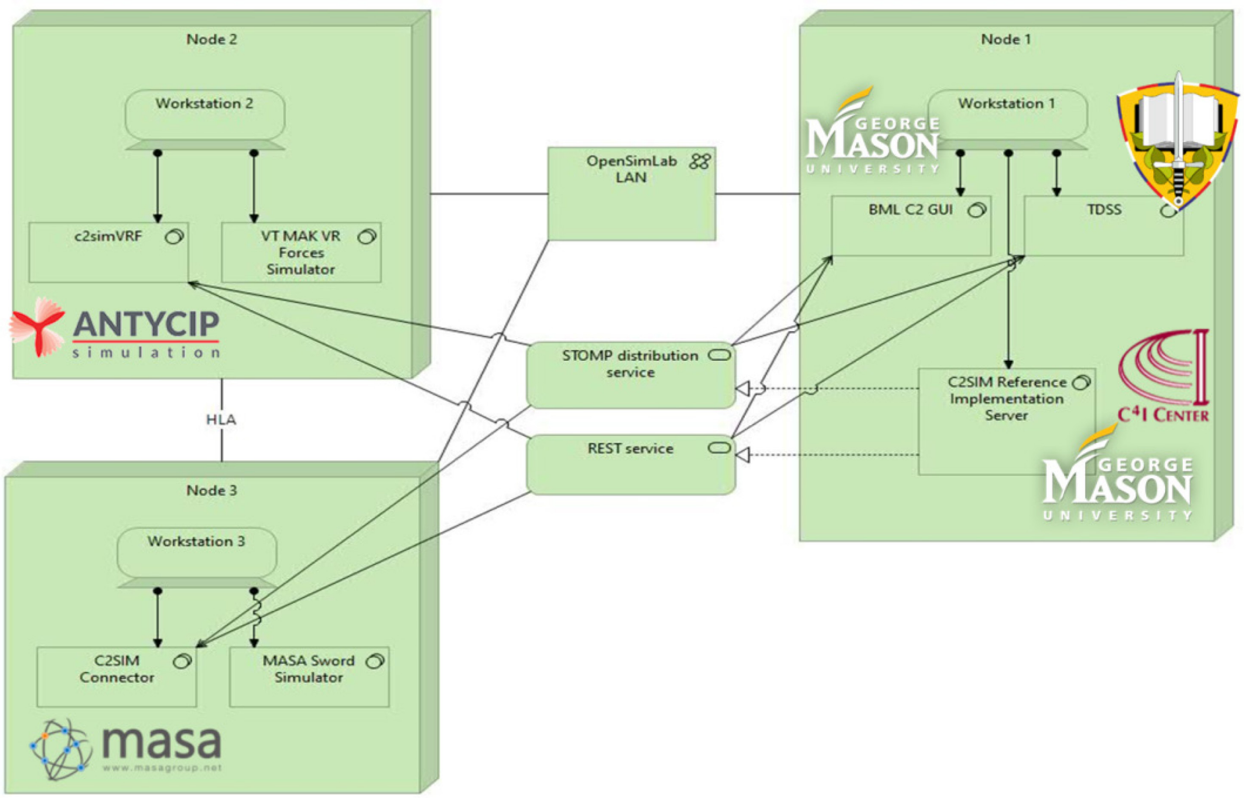

Figure 3-1: NAF v4 P3 View (Resource Structure and Connectivity) of the R2CD2 Prototype.

The scenario designed to support the R2CD2 project goals had the following simulation objectives:

- Detection and Identification of enemy robotic units utilizing UAxS and sensors;
- Situational Awareness (SA) augmented with external decision-making support tool;
- Experimentation about defence against UAxS using UAxS;
- UAxS employed in urban environment both in land and air domain; and
- Distinguish human-robot interaction according to three LoAs.

Based on the above requirements, the scenario shows a mission for protecting the troops and populations against hostile UAxS. A team of Unmanned Ground Vehicles (UGV) escorts a human platoon in a city while a swarm of Unmanned Air Vehicles (UAV) performs a reconnaissance of the area searching for threats. As soon as hostile air drones show up, UAVs generate reports on enemy activity for UGVs which activate a two levels defensive system based on a safety bubble where, according to the distance of the threat, the countermeasures increase from non-kinetic (jamming or capturing) to kinetic (shooting).

3.1.1.3 Experimentation

The Autonomous System use case demonstrated that the C2SIM baseline made of Core+SMX+LOX can be extended to execute scenarios involving simulated AS interacting with C2 Systems according to their level of autonomy. The ASX was tested both in isolation during R2CD2 project, executing a peculiar scenario, and in complex scenario during coalition scenarios. In the last case, C2SIM messages formatted according to slightly different schemas flowed between different systems at the same time, proving that ASX can be used without conflicts with messages supporting only Core+SMX+LOX.

In particular, ASX was experimented during CWIX 2019 used by the R2CD2 project demonstrator, which participated as capability CC-298 NATO M&S COE C2SIM R2CD2 EVO 2.0. As for all the tests during CWIX, each trial was basically a message transmission with a producer, one or more consumers and eventually a distributor or mediator. CC-298 did nine successful tests, as producer or consumer or in both roles. The tests successfully validated that ASX can be employed in a compliant coalition C2SIM environment.

Additionally, the ASX was tested during the group's MiniEx for the validation of the standard. A more complex common coalition scenario was executed and the experimentation was conducted in the form of a distributed mission planning exercise, at brigade-level, supporting a fictional nation called Bogaland.

3.1.2 Cyber Warfare in Operational Military Training (USA)

3.1.2.1 Objectives

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 Implementation Server supports to the latter, which is quite important because military forces must be prepared to function effectively in a cyber-active environment.

3.1.2.2 Implementation/Architecture

The GMU C4I and Cyber Center's work 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 imposing Cyberspace Electromagnetic activities (CyberEW 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.

3.1.2.3 Experimentation

The Cyber Warfare use case demonstrated how C2SIM supports user C2 information systems, also called C2IS or Mission Command Information Systems (MCIS), training in an operational environment during Defensive Cyberspace Operations (DCO). Threat offensive cyber actions, that is Cyber attack, is accomplished by modifying C2SIM server system messages between C2 and Simulation systems that implement the SISO C2SIM Standard, in a way that reflects impact of threat Cyber behaviors (attacks) on C2, simulation, and the network they share. Messages were either simply deleted or modified to represent the effect of an attack that has compromised connected systems. In either case, the C2 Systems and their military users received stimulus accurately and effectively representing the effects of an actual Cyber threat/adversary. An early test of these concepts was completed by MSG-145 in CWIX 2019.

3.1.3 Mission Planning for Army (Norway)

Army operations are highly complex due to the large number of systems and units taking part. To achieve combined arms effects the orchestration of systems and units need to be tightly coordinated and executed.

This use case covers a Brigade HQ conducting hasty planning for a battalion Course of Action (COA) using simulation-supported tools for COA development.

This use case will provide feedback to the C2SIM *Land Operations eXtension* (LOX).

3.1.3.1 Objectives

The purpose of the experiment was to evaluate the potential of adding simulation support to the traditional planning. The Norwegian Defence Research Establishment (*Forsvarets Forsknings-Institutt* – FFI) has developed Simulation-supported Wargaming for Analysis of Plans (SWAP), which was used as the simulation tool during the experiment. The objective of SWAP is to research and demonstrate simulation of an executable COA, revealing strengths and weaknesses of the plan. The hypothesis is that adding simulation support to Command and Control (C2) systems will make planning better and faster than traditional planning, adding value to the planners.

3.1.3.2 Implementation/Architecture

SWAP is a research prototype of a decision support system for military planning, with limited functionality. It consists of a cloud-based simulation system and is developed according to the Modelling and Simulation as a Service paradigm. SWAP provides basic terrain analysis to support COA development – this includes tactical route planning and vantage points. A web-based user interface allows the user to develop a COA consisting of basic tasks and associated control measures. The resulting COA is then simulated to reveal possible consequences. SWAP uses a data model based on SISO C-BML Light formatted in JavaScript Object Notation (JSON) to capture a digital COA.

The order of battle was imported using Military Scenario Definition Language (MSDL) during the experimentation. The order of battle can be imported from the Norwegian C2IS (NORCCIS). Reports may also be presented in NORCCIS during COA simulation.

3.1.3.3 Experimentation

In February 2019, FFI conducted an experiment with 52 final-year cadets from the Norwegian Military Academy. The cadets were divided into groups and tasked to make simplified decision briefings for two different battalion operations, using SWAP and the traditional planning tools (paper maps) respectively. A fictive scenario used multiple times in army planning courses was used. The cadets had a very short time to learn how to use SWAP before the experiment started (Figure 3-2).

The cadets were given two hours for each battalion operation. During the simulation, the users could see units moving and status information regarding health, fuel and ammunition being updated. The simulations used aggregated models.

The cadets took advantage of the functionality of SWAP when preparing their decision briefings. They were able to develop their COAs with the limited number of tasks, but indirect fire, missile and Close Air Support (CAS) were some of the missing tasks. The possibility to specify the start timing of tasks and a synchronization matrix were also suggested additions, together with improved graphical user interface (standard symbols and expressiveness). The possibility to change the task organization was also requested.

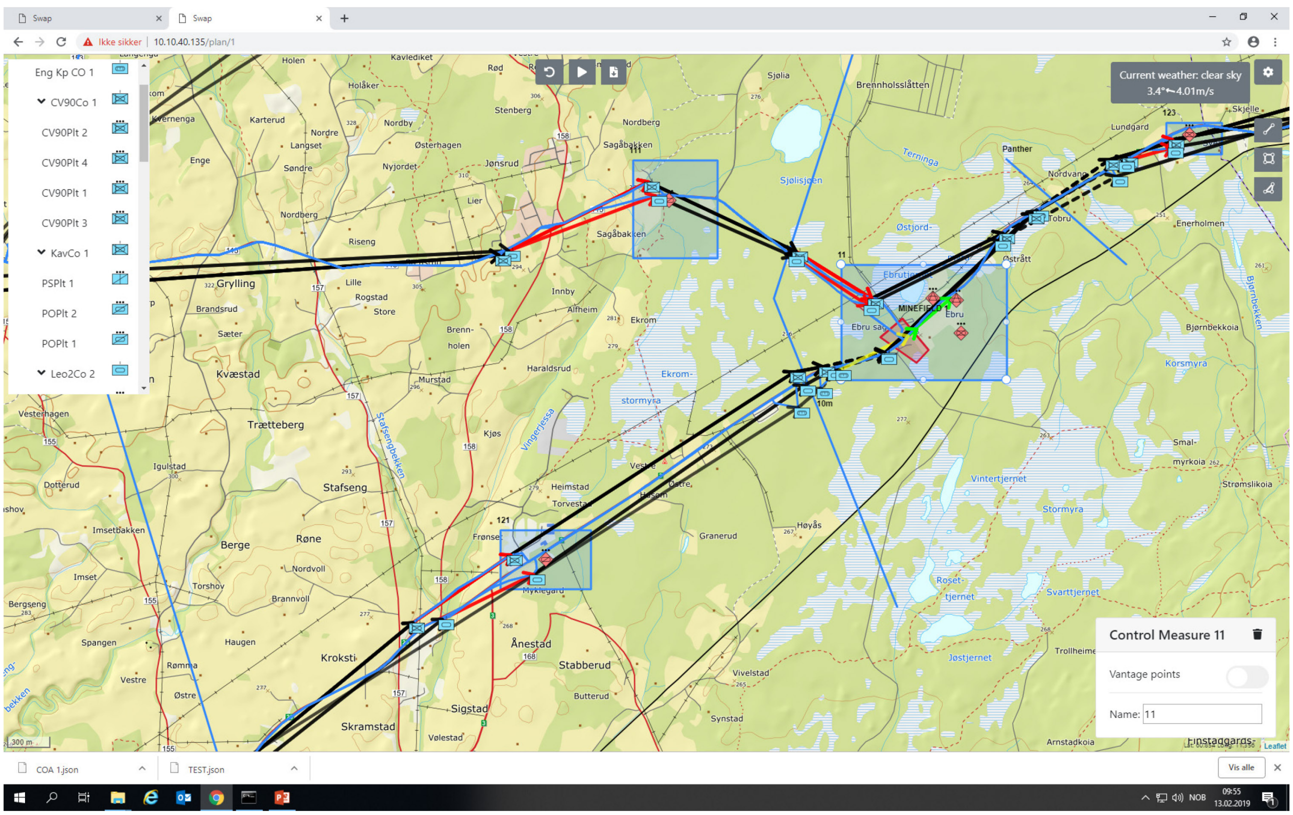

Figure 3-2: SWAP Web USER Interface.

They wanted the simulation speed to run much faster, and the ability to change the speed during the simulation. They also wanted to stop the simulation, make decisions and possibly changes to the plan, and then continue from current state.

The cadets could see the potential of a tool for terrain analysis but wanted the possibility to specify further aspects like accessibility, concealment, cover and threat.

For COA simulation the requirements are that a simulation execution should not take long, and the users should be able to change the speed during the simulation. It is also desirable to be able to stop the simulation, make decisions and possibly changes to the plan, and then continue from current state.

Terrain analysis tools for finding vantage points to identify good positions and tactical route planning were useful for creating the COA. The users however requested the possibility to specify further aspects like accessibility, concealment, cover and threat.

The feedback given was based on using SWAP, but some of it may also apply directly to C2SIM, for instance addition of new tasks, task associations/timings and aspects to consider during terrain analysis. Outputs of using SWAP are given in detail in [7], [8].

3.1.4 Joint Mission Planning (United Kingdom)

3.1.4.1 Objectives

This use case was developed to show how C2SIM-enabled C2 Systems could be used to support Joint Mission Planning (JMP). Mission planning has always been the major function of a headquarters at all levels of command in the Military Decision-Making Process (MDMP). Nations have developed similar processes based on planning and execution. This is often referred to as Plan, Refine, Execute, Evaluate or Assess process. Until the development of digitized C2 Systems this process was manually driven and to some extent this remains the case although as UK strategy and policy has highlighted simulations that are interoperable with digitized C2 Systems should be increasingly used to support the Military Decision-Making Process. Within the UK, joint mission planning processes are defined in AJP-05, Allied Joint Doctrine for the Planning of Operations [9].

The UK led an experimentation to demonstrate a credible Mission Planning and Course of Action analysis capability aligned with the NATO Comprehensive Operational Planning Directive (COPD) [10] processes using C2SIM. This demonstrated how the UK can connect national and coalition partners' C2 to Simulation systems together to enhance mission planning, mission rehearsal and decision support to operations.

3.1.4.2 Implementation/Architecture

The UK team based its work on a specific joint vignette: conducting a Non-combatant Evacuation Operation (NEO). This work used an updated UK test-bed architecture designed around the draft SISO C2SIM Standard. The vignette was chosen for a number of reasons: its joint, multi-agency nature; relatively short duration; and topicality, as an example of the type of operation which is well-defined by current doctrine [11].

Operational details were worked up as a vignette of the wider scenario developed for the CWIX 2019 and MSG-145 MiniEx. This is described more fully in Annex B. The system architecture for the UK capability is given in Figure 3-3. This is the UK stand-alone test-bed capability hosted in a commercially procured cloud computing environment.

This architecture is built around a locally running instance of the GMU C2SIM Web Service (WS) which uses Simple Text Oriented Message Protocol (STOMP) and Representational State Transfer (RESTful) messaging to exchange C2SIM messages between systems. The WS is a publish-subscribe system. The principal systems used were a surrogate C2SIM Common Scenario Editor (CSE) developed by Thales UK and a C2SIM-enabled variant of VR-Forces, a constructive Computer Generated Forces (CGF) simulation from VT MÄK.

Figure 3-4 shows a screen shot of the CSE. This has the ability to prepare data for initialization, Orders of Battle (ORBATs), tactical graphics and orders. It can also display C2SIM entity and unit location reports communicated via the WS.

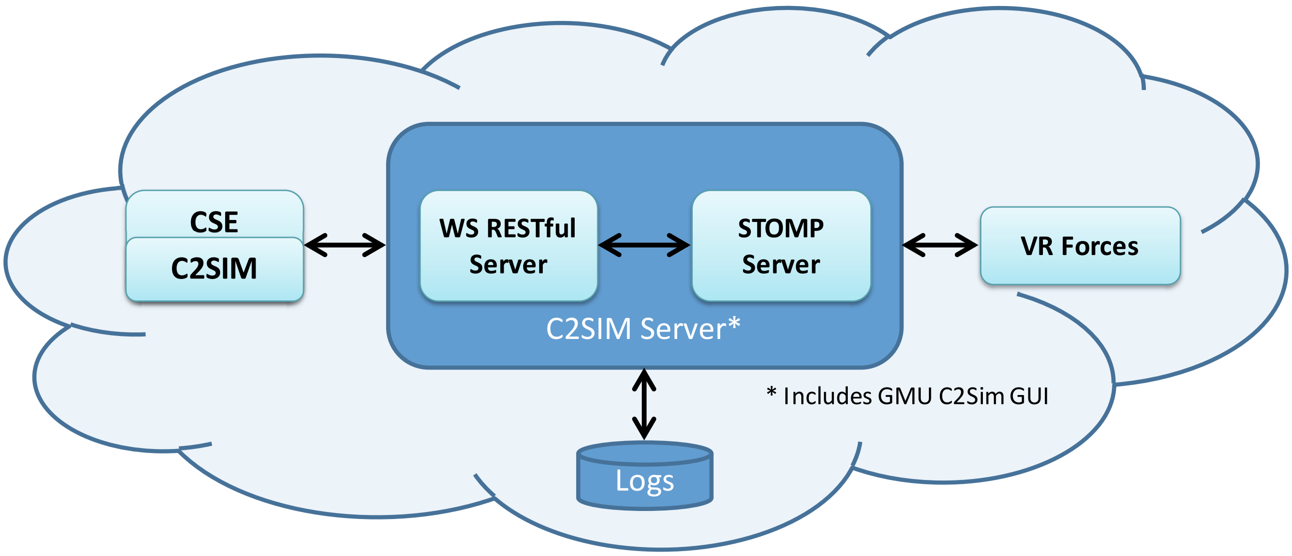

Figure 3-3: UK Testbed Architecture.

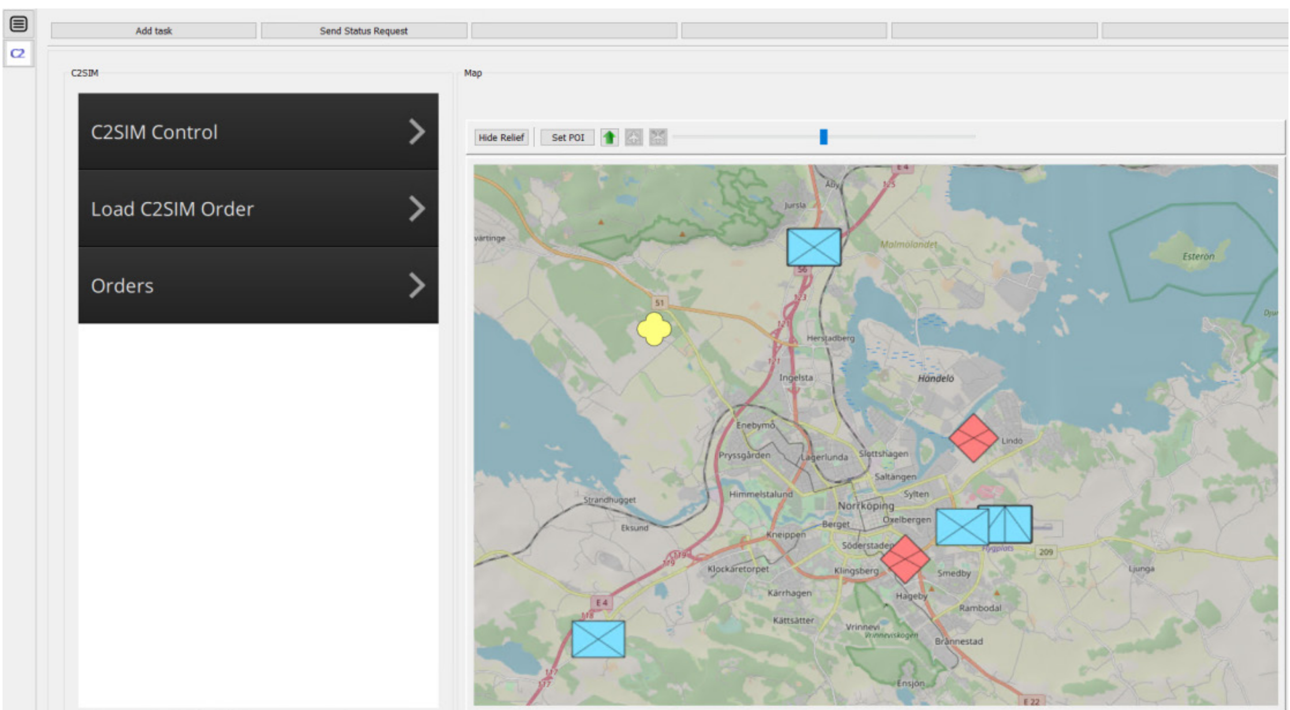

Figure 3-4: UK Common Scenario Editor.

Figure 3-5 shows the user interface for VR-Forces.

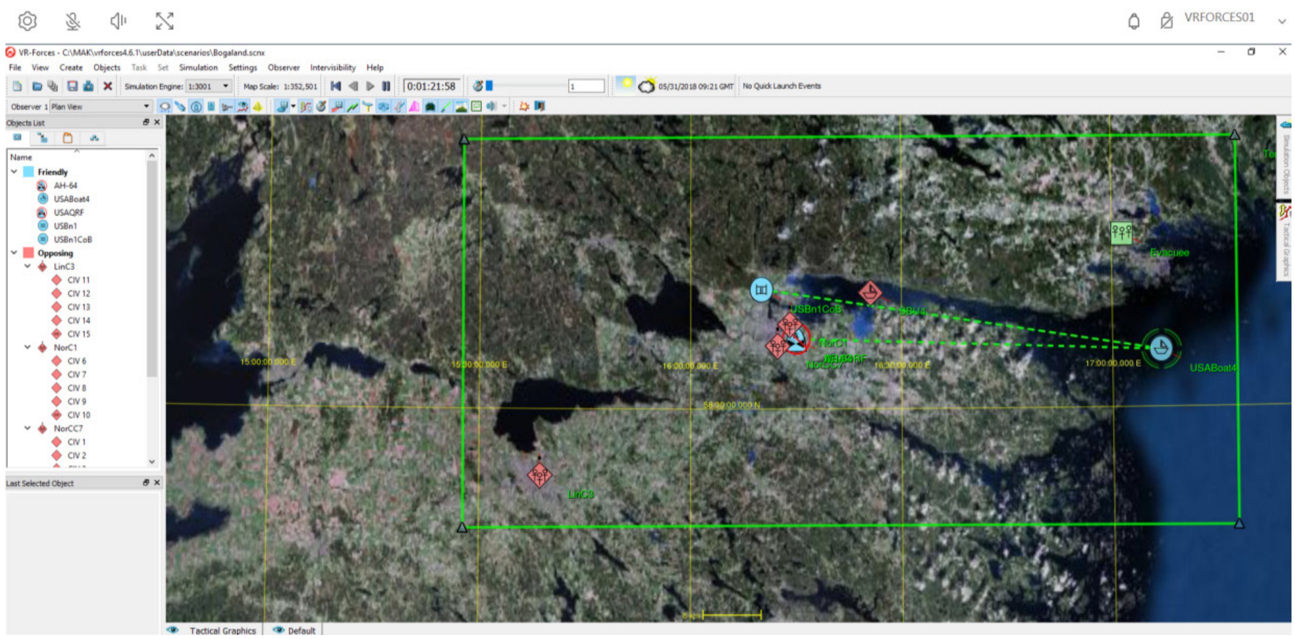

Figure 3-5: VR-Forces.

3.1.4.3 Experimentation

This configuration permitted the UK to test an isolated C2SIM-enabled prototype with all elements operating on cloud-hosted computers. In the event there were a number of technical problems with this approach, mostly relating to running of the simulation graphical front-end in a cloud. Two different Cloud Service providers were tried with widely differing degrees of success. This effort caused some delays and to mitigate the risk to the MSG-145 experimentation (CWIX and the MiniEx) the UK reused some of its earlier test-bed capability based on a C-BML-enabled Joint Semi-Automated Force (JSAF) simulation.

The experimentation highlighted that the LOX of the C2SIM as it stood at the time was missing some ActionTaskCode values needed specifically for this vignette and that the guidance for coordinating tasks needs to mature, e.g., tasking evacuees to board and disembark from a helicopter. That deficiency was reported to the SISO C2SIM PDG and was corrected.

3.1.5 Air Operations Using Tactical Data Links (France and Germany)

3.1.5.1 Objectives

France and Germany together proposed to lead an experimentation to assess the C2SIM LDM extension mechanism by working on a TDL extension. TDL represents a key capability in modern operations as it provides a near real-time mean to share tactical information between participants improving situation understanding, and to coordinate mission by providing a standard way of exchanging commands and control information among participants.

TDL are currently implemented on real systems (platforms, weapons and C2) using Standardization Agreements (STANAG) such as Link 11, Link 16, Variable Message Format (VMF) etc. Those STANAGs are difficult to implement due to the complexity of the systems behind, and it is a real challenge for simulation systems to implement them. One reason is that specific requirements related to training such as capability to move backward and forward or to restart an exercise are hardly compatible with TDL time management constraints. Moreover, certain TDL concepts such as track correlation are much easier to implement in a simulated environment than in a real system.

Until now C2SIM and previous initiative have focused on exchanging operational messages without considering the special case of TDL which have been occasionally used in simulators. With the increasing number of TDL platforms and the growing importance of tactical procedures it is now important to consider how simulations and simulators may exchange with TDL units in order to create efficient training systems.

France and Germany have developed extensions to the unified C2SIM LDM to support TDL information. For that, extension to the Core Logical Data Model was created addressing the main concepts of TDL without focusing on one particular Data Link. This model was then implemented, and an experimental version was integrated into CGF and a C2 surrogate system.

By developing this extension, feedback on the C2SIM extension mechanism was provided to the C2SIM PDG.

3.1.5.2 Implementation/Architecture

DirectCGF is a DIGINEXT CGF based on simulation Engine DirectSim (French MOD middleware) for high fidelity Battlespace generation. It owns a full set of models ready to use (platforms, sensors, weapons, electronic warfare, and communication) including TDL automatic and intelligent behavior. It maximizes reuse and productivity gains due to its modular architecture allowing users to add dedicated plug-in. Fully interoperable (Distributed Interactive Simulation (DIS), High Level Architecture (HLA), Standard Interface for Multiple Platform Link Evaluation (SIMPLE), C-BML, Data Distribution Service (DDS)), it can be interfaced with other solutions for multi-level tactical simulation runs.

STARLINX is a DIGINEXT C2 System designed to operate within a TDL Network (Figure 3-6).

A first TDL C2SIM capability was developed both for DirectCGF and STARLINX based on C-BML. It provided great lessons learned to extend C2SIM with a dedicated TDL extension. Hence, this experience was the foundation to clearly identify the required components to reproduce the generic TDL mechanisms. It has proven the feasibility of the approach and therefore the C2SIM TDL extension was proposed in a proper way.

The development of the C2SIM TDL extension was built according to the standard process (see Section 3.5.5). Its implementation was performed in using DirectCGF and C2LG GUI (C2 Lexical Grammar – FKIE C2 surrogate). Demonstration of its usability to order and report Air platforms was successfully proven by connecting both systems during scenario execution. The C2SIM TDL extension also covered the initialization of systems which was a key point to initialize with common data DirectCGF and C2LG GUI.

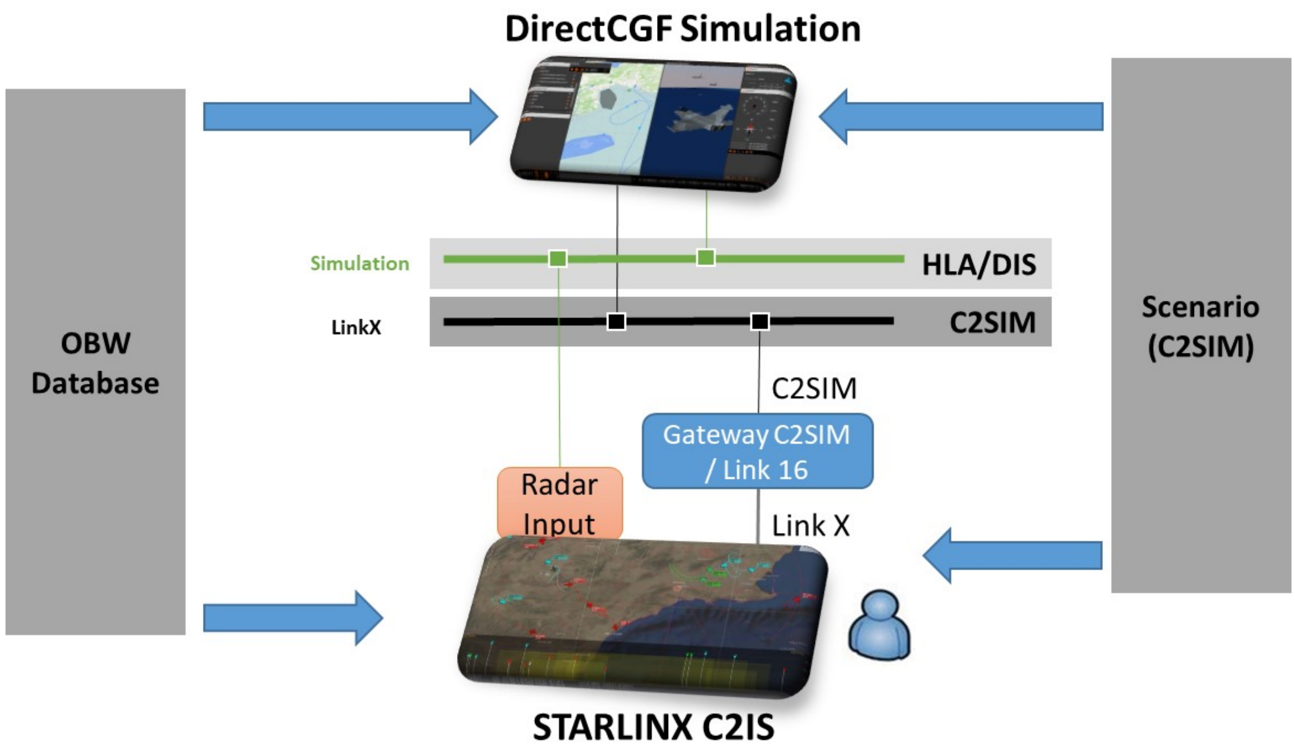

Figure 3-6: Air Operations AOX Capability Architecture.

3.1.5.3 Experimentation

In order to assess TDL extensions and to reach out the C2 and M&S communities two experiment events were organized:

- I/ITSEC 2017: it focused to address STARLINX and DirectCGF C2SIM interoperability as a proof of concept regarding C2SIM capabilities. The demonstration was part of Operation Blended Warrior (OBW).
- I/ITSEC 2019: it highlighted the usability of the C2SIM extension process averaging additional improvements by connecting DirectCGF and C2LG GUI, as a C2 surrogate.

Both events were located in the NATO booth with local operators to run the systems and to execute a fictitious scenario involving air assets under the control of a command post C2. The scenario was more complex for I/ITSEC 2019 with the Air Defence systems and cruise missiles involved.

3.1.6 Command Post Training (Germany)

The integration of Command and Control (C2) systems in training and exercises has become very important (themed "Train as you fight") in the last decade. In the last years Germany successfully deployed MSDL and C-BML standards for coupling national legacy C2 with legacy simulation systems in operational exercises at the German Army training center.

The use of the newly developed C2SIM Standard should enhance the interoperability capabilities of the used simulation systems at the German Simulation Training Center located in Wildflecken, Germany, and therefore will allow further nations (e.g., from NATO or PfP countries) to profit from services provided by the German training facility, given that the training units have also a compatible C2SIM interface for their used operational C2 Systems. Hence the ad hoc training and exercises setting for every nation or military unit willing to be trained at the German Army simulation center will be easier.

3.1.6.1 Objectives

The main objective was primarily to evaluate the newly developed C2SIM by implementing the suitable interface for the German legacy simulation system KORA and for the C2LG GUI (which has played the role of a simulating C2 System for testing issues). We have been concentrating primarily on the Land Operation Extension (LOX), which is still the main aim of the German Simulation Training Center. Nevertheless, we addressed in bilateral German-French the testing of air-based operations with TDL (see Section 3.5.5), which could also be incorporated in a Joint national or multinational training events.

To be able to improve the implemented C2SIM interface, it was helpful to participate in different testing events (see below) so that many lessons learned could be gained and used in the further improvement of the implemented interfaces.

The evaluation of the use of the C2SIM Standard is helpful to assess the maturity of the C2SIM and also to check how far and to which extent “unstructured information” can be really represented by the new C2SIM LDM. Furthermore, also the provided extension mechanism and process (especially for LOX) will be evaluated.

3.1.6.2 Implementation/Architecture

KORA is a German legacy constructive simulation system for officers and staff officers training. It simulates relevant aspects of land, air and maritime operations and encompasses the entire scope of service within the Armed Forces including connections to command and control systems. The system is able to simulate military and/or civil-led operations in the field of crisis response. The main focus is the training of the military staff organizations at the operational and all tactical levels. KORA enables simulation-assisted exercises for HQs, component commands (LCC, ACC, MCC, SOCC), brigade and task force HQs respectively, non-article 5 crisis response operation environments.

In the last decades, several CAXs (Computer Assisted eXercices) have been achieved by using and interacting with the German Legacy C2 System (FISH) at the national level as well as with other C2 Systems from other nations on multinational level (such as the French Système d’Information pour le Commandement des Forces (SICF), Système d’Information Règimentaire (SIR), and the commercial C2 System SitaWare, NATO’s Integrated Command and Control (ICC) and Maritime Command and Control Information System (MCCIS)). KORA has many interfaces allowing it to interoperate with different C2 and Simulations systems using different standards, such like MSDL, C-BML, HLA (RPR FOM and NATO Education and Training Network (NETN)).

To evaluate the new C2SIM Standard, an Interface has been continuously developed and improved in the last two years to enable interoperability with different C2 Systems and by testing the exchange of different reports and orders from and to the C2 Systems. These main tests are specified in the next section in more details.

3.1.6.3 Experimentation

For validation purposes several experimentations with the combat simulation system KORA have been conducted to:

- Gain experience about the difficulties and needed efforts for implementing the new C2SIM Standard,
- Collect information about missing data model in the core LDM, and
- Gain insights for the effort needed for the needed LDM extensions (esp. for LOX).

Therefore, DEU participated with KORA to several test/experiment events:

- I/ITSEC 2017: For Germany, it was a first proof to validate the implementation of the interface using the C2SIM approach. The systems involved in this demonstration were: C2SIM Sandbox (USA), Joint Semi-Automated Forces (JSAF) (UK), VR-Forces (USA) and KORA (DEU). As terrain the “Bogaland” area was used (from the PfP VIKING exercises); this is an area in the northwest of Stockholm, Sweden. The main test aim for DEU was to prove the correct data exchange between KORA and the C2SIM Sandbox. Further details will follow below in Section 3.3.
- CWIX 2018: The CWIX offered a very good opportunity to evaluate the current version of the C2SIM Standard developed within the scope of the C2SIM-PDG. Germany/IABG participated in a first coupling test in the context of I/ITSEC 2017 with the simulation system KORA. This first step sets the stage for more extensive testing with the redesigned standard. In order to gain further insights, it was decided in consultation with the German Customer / end user to take part in the CWIX’18, in order to:
  - Support the goal of familiarizing operational national and NATO staff with the C2SIM theme; by presenting C2SIM in a place where the communities of NATO C2 and Simulation come together.
  - Support the goal of developing the SISO C2SIM Standard by using the standard design in a test environment.
  - Better understand how C2SIM can be used.

  In this Experiment KORA simulated a UAV attack and ground forces. The Norwegian C2 System NORCCIS sent orders to KORA and VR-Forces and received KORA reports back using the C2SIM Sandbox. This basic testing was successful, it suffered indeed from the small amount of data (reports and orders) sent and tested between the C2 and Simulation systems.
- I/ITSEC 2018: DEU participated with KORA to the MSG-145 demonstration at the I/ITSEC 2018 on the NATO booth. The same version of C2SIM (as in the CWIX 2018) as well as the same scenario (small counter terrorism scenario) was used here. The only difference was that the testing experiment has been achieved in a distributed architecture in which four systems (KORA, SWAP, VR-Forces and C2SIM GUI) were located locally at the NATO booth and another three (NORCCIS, JSAF and the GMU communication infrastructure) have been operated from different places (see Section 4.4.3).
- CWIX 2019 and MiniEx 2019: Here the main task for DEU/KORA was to test the effort needed for the LDM extension for Land Operation based on the Product description delivered by C2SIM PDG. Analog to the CWIX 2018, KORA was here also able to exchange reports and orders with C2 Systems (see Section 4.1.3 and Section 4.2). The main difficulty for DEU/KORA here was the missing of a process to describe the LOX implementation process itself.
- I/ITSEC 2019 and German-French Experiment: Based on the lessons identified regarding the use of the C2SIM Standard and especially the difficulty experienced by the developing of LOX during the

CWIX2019 and MiniEx 2019, Germany and France tested a new extension mechanism for Air Operations eXtension (AOX) as well as for Ground Combat eXtension (LOX) (see Sections 4.4.4.1 and 4.4.4.2, List of Acronyms).

3.1.7 C2 System Training (New Zealand)

The New Zealand Army has selected SitaWare from Systematic as its C2 System. As SitaWare is rolled out to regular army units, C2 training is required to teach C2 operators how to create plans and orders. With the development of C2SIM there is the potential for operators to see their plans unfold in a simulation.

3.1.7.1 Objectives

The objective for New Zealand was to implement the C2SIM Standard and evaluate its potential for enhancing C2 System training by connecting to a simulation. Demonstrating the utility of C2SIM is expected to open new opportunities to use simulation for course of action analysis.

New Zealand decided not to implement C2SIM for SitaWare to avoid repeating the work by the USA. Instead, New Zealand implemented a C2SIM interface for Virtual Battlespace 3 (VBS3) by Bohemia Interactive Simulations. VBS3 was chosen as the target simulation because it has been in service in the New Zealand Army since VBS version 1.4 and is widely known.

3.1.7.2 Implementation/Architecture

VBS3 is a virtual/constructive simulation that originates from a first-person computer game. It is typically used for training teamwork and coordination at the squad and platoon level. It supports DIS and HLA, which allows it to join larger federations or to be used as a 3D viewer. Constructive units are controlled with behavioral waypoints combined with rules of engagement. There is also a custom scripting language that is used for designing complex scenarios with triggers or custom behaviors. Custom plugins must use the scripting commands to interface with VBS3.

New Zealand developed a VBS3 interface that used the C2SIM Core, SMX and LOX. The range of types of C2SIM orders available in the LOX far exceeded the types of waypoint behaviors available in VBS3. Most orders were mapped to simple “MOVE” waypoints, but with different rules of engagement. There are other factors in the VBS behavioral modelling, such as morale and combat proficiency, which may result in orders not being followed as the commander expected.

3.1.7.3 Experimentation

New Zealand joined the MSG-145 research task late and had not participated in earlier CWIX tests. Furthermore, we did not have access to the required network. Participation was limited only to the MiniEx, which was run on a VPN over the internet. To reduce the risk on the full exercise with an untested system, only two small boats were simulated in VBS3 in the Bogaland scenario, one Blue and one Red. A specific maritime operations extension had not been developed, but the C2SIM Core and LOX were acceptable for patrol boats, which essentially operated like ground vehicles on water.

3.2 REFERENCE ARCHITECTURE

A lesson identified in the NATO activity MSG-085 [1] was that a Reference Architecture (RA) for C2SIM interfaces should be developed to facilitate C2SIM environment design. Therefore, a study has been performed in the framework of MSG-145 to make an initial step towards such a reference architecture for C2SIM using a similar approach as was used within MSG-136 "Modelling and Simulation as a Service (MSaaS): Rapid deployment of interoperable and credible simulation environments" where a reference architecture for MSaaS has been developed. The objective of this study was to introduce the concept of a Reference Architecture for the C2SIM Integration Platform (that enables connecting simulation environments with C2 environments). An RA provides templates, guidelines, options, and constraints for making design decisions with regards to a solution architecture and solution implementation for the development of C2SIM Integration Platform solutions.

Annex A provides the results of the C2SIM RA study. It should however be stressed that the work only resulted in an initial step towards RA development and didn't result in a completed RA.

3.3 C2SIM SANDBOX

Figure 3-7 shows the architecture of the C2SIM Sandbox, which contains a full set of C2SIM architectural elements (C2 System, simulation system, server) that are remotely accessible by an HTML5-compliant web browser via Internet Virtual Private Network (VPN). This allows testing or demonstration of the Sandbox configuration as a working system-of-systems and also allows its use for remote testing or demonstration of similar system components under development.

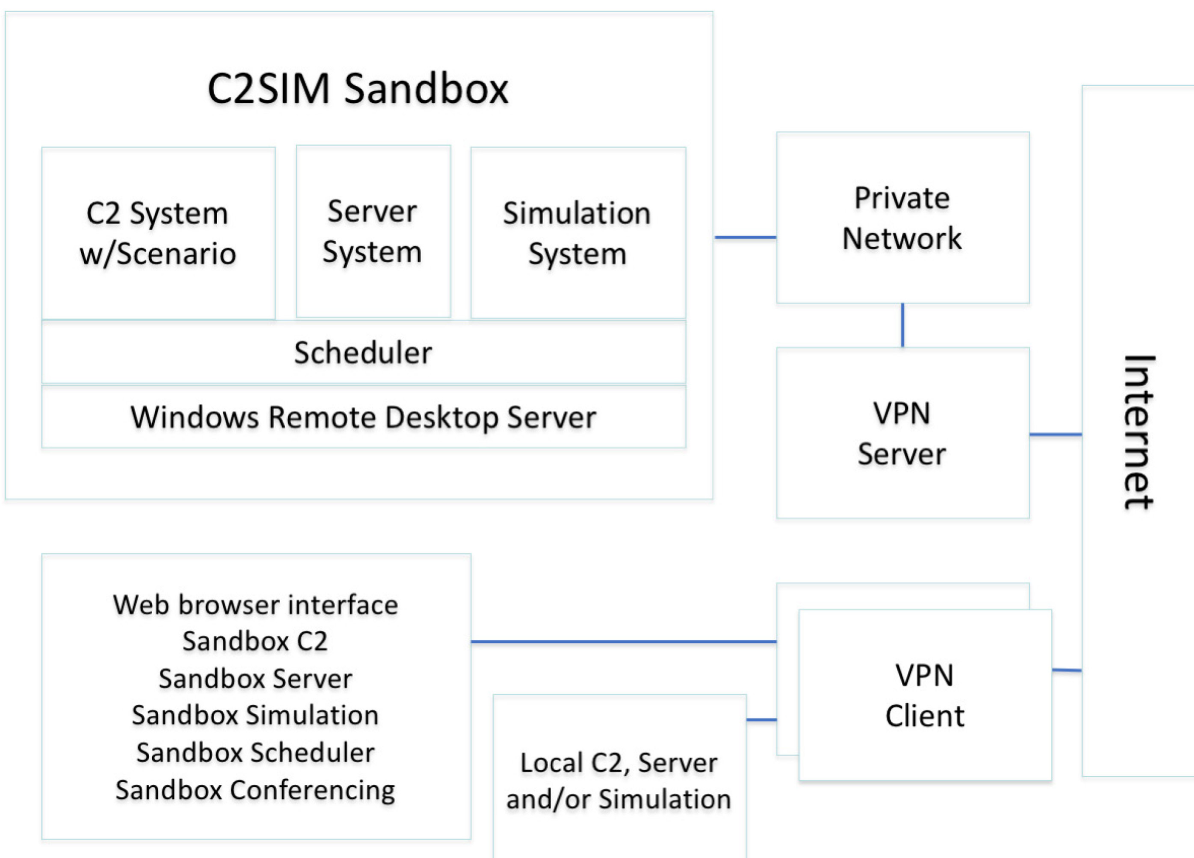

Figure 3-7: C2SIM Sandbox Architecture.

3.4 MASTERING INTEROPERABILITY

In the past, simulations were most of the times only coupled with other simulations and the exchanges were made exclusively with the support of dedicated technologies (DIS, HLA). For the development and the execution of Distributed Simulation, an engineering and execution Process (DSEEP) [12] has been standardized. The DSEEP process is defined with seven steps:

1) Define the simulation environment;
2) Perform conceptual analysis;
3) Design simulation environment;
4) Develop simulation environment;
5) Integrate and test simulation environment;
6) Execute simulation; and
7) Analyze data and evaluate results.

Simulation is today used in multiple contexts: operationally from forces readiness to decision support and for acquisition purposes throughout the life cycle of armament programs (systems design to systems qualification).

In these broader scopes, simulations are coupled with operational systems. The resulting integrated systems maybe called, by the French procurement agency for defence, Systems Using Simulation (SUS). The development of such systems can be relatively complex from an integration point of view. For C2 and more largely for C4ISR, the interoperability and integration issues with simulation have been supported for a long time by the simulation community with the emergence of exchange models that have become standards (MSDL, C-BML to name a few).

As a process exists for the development of distributed simulation, the development of a SUS, because of technical specificities inherent to the mixing of real and virtual elements, should follow an **engineering process**, from the expression of the needs to the validation of the system. For SUS design, one may think to use the DSEEP but the DSEEP is not applicable: it is not designed to consider other systems than simulation. For example, in the DSEEP step 4.1 "Develop simulation data exchange model", the objective is to define a Simulation Data Exchange Model (SDEM) to formalize the "contract" among member applications necessary to achieve coordinated and coherent interoperation within the simulation environment whereas the architect of the SUS would need to develop a data exchange model to formalize the contract among member applications, regardless the simulation environment.

Strategies for designing interoperability models exist in between two paradigms: the first one consists of capitalizing and standardizing the process to develop the model (e.g., DSEEP is the result of the standardization of a process), the second one consists of capitalizing and standardizing the model itself (e.g., DIS is the result of standardizing the model). Between these two paradigms, HLA is a pretty well-balanced approach. It includes and standardizes both specifications to define the format and syntax for recording information and a reference model (Real-Time Platform Reference Federation Object Model (RPR FOM)). With HLA, the user can start to design the simulation data exchange model from a white page or can extend a standard model (e.g., RPR FOM and extension modules).

Both paradigms come with their advantages and drawbacks. On one hand, the standardization of data exchange models allows having models highly reusable; data exchange models definition requires few or no design; the models are mature and well documented. This comes at the cost of no flexibility and sometimes, workarounds to adapt the model for specific requirements: the model is modified savagely leads inevitably to interoperability issues (misuse of data fields or adaptations of the models to cope with requirements). On the other hand, the standardization of a process allows mastering the definition of every field of the data exchange model; the model is highly flexible, has just the right size and if designed correctly, the process allows capturing and capitalizing the information exchange requirements for every single data field of the model. This comes at the cost of some significant effort to define exchange data models.

While time passes, systems of systems are becoming more and more complex, are evolving faster and faster. With such a trend, mastering the exchange requirements and generating an exchange data model fitted for the needs maybe more efficient than reusing static models that are becoming bigger and bigger, and difficult to use (e.g., JC3IEDM). The standardization of the process, and efficient tools to compare information exchange requirements, may become the best way to handle interoperability.

To master the (C2SIM) interoperability, MSG-145 group followed the process approach and produced a guide, usable by engineers (architects, designers, developers, etc.) over their usual engineering process. This guide describes a generic process for interoperability models development. The process is split in two, first one for the generation of execution data models (with seven tasks), and second one for the generation of initialization data models (with three tasks). See Annex C for further description. The main objectives targeted with the implementation of these processes are to:

- Identify and generate exchange models for interfaces among systems of the SUS:
  - Based on the use of open standards, including their existing enrichment or extensions;
  - Building new extensions of these open standards when required; and
  - Ensuring the completeness of the definition of the exchanges, throughout each design steps of the engineering process, from the initial expression of the needs (end user needs, conceptual scenario, etc.) to the specification of the systems of the SUS with theirs interfaces.
- Maintain traceability throughout the process, from initial expression of the needs to the production of exchanged data models.

3.5 C2SIM EXTENSION

3.5.1 Ontology Theory

The ontology concept is borrowed from philosophy to create a model of existence. In computer science, ontologies are often used as conceptualization of knowledge to share and reuse it between software components. In this field, knowledge is modelled with primitives such as classes, relations and attributes following specific design criteria (Gruber, 1997). These criteria include clarity (definition independent of context and complete), coherence, extensibility, minimal encoding bias and minimal ontological commitment. However, an ontology is usually a trade-off of these criteria, as knowledge depends on context. Therefore, ontologies are usually modelled for specific domains covering context information and taking into account the intended usage of the ontology. If so, ontologies are modelled according to so-called competence questions to adjust the knowledge to its application.

The World Wide Web Consortium (W3C) offers a wide selection of standard formats for ontologies. These include Resource Description Framework (RDF), RDF Schemata, and Web Ontology Language (OWL).

An ontology using the OWL formalism consists of a taxonomy with classes, properties and a set of individuals. These are linked to each other with axioms that can for example define classes if they are restricted with its properties.

These OWL axioms that provide semantics with means of mathematical set theory (with axioms for union, intersection, and complement of classes, i.e., sets of individuals) allow to infer additional information from explicitly modelled knowledge. This reasoning capability is also provided by OWL.

3.5.2 C2SIM Standard Approach

Standards allow simulations and other applications to produce a shared representation of reality. When discussing data structure and reference models, the first SISO standards that come to mind are the Object Model Template" (OMT), IEEE 1516.2 [13] and the RPR FOM, SISO-STD-001-2015 [14]. These standards deal with format and syntax for HLA information and guidance, rationale, and interoperability modalities for the interconnection of HLA federates. This is obviously not applicable for C2SIM; C2SIM is not directly linked with HLA and its set of standards. Even though they share the same objective, to provide a frame for information exchange between distributed applications, the interest of the HLA here is limited: C2 Systems rarely or never implement HLA interfaces. Their focus goes to structuring data independent from architecture and communication protocols.

Two existing SISO standardized languages are expressed in a format independent from any communication protocols: the Military Scenario Definition Language (MSDL), SISO-STD-007-2008 and the Coalition Battle Management Language (C-BML), SISO-STD-011-2014. MSDL is used to support military scenario development; scenarios can be seen as the cornerstone of C2SIM initialization; C-BML is used for exchanges of orders and reports i.e., tasking and reporting. Tasking includes Orders and Requests; the only distinction between the two for purposes of this document is that an Order comes from an entity with command authority and thus is expected to be obeyed if it is physically possible to do so, whereas a Request is fulfilled at the discretion of the entity to which it is directed. These two standards are the seedbed in which the current C2SIM developed; C2SIM seeks to harmonize their functions and make those functions extensible.

The C2SIM Product Development Group has consolidated the functions of both C-BML and MSDL with the goal to create a unified standard that provides seamless integration among C2 initialization, tasking, and reporting with simulation systems and robotic systems. This unification endeavor goes well beyond simply merging the standards together: the scope, initially military-centric, is enlarged to all domains; structuring of data, formerly only available in the physical domain is now available both in the logical domain (OWL ontology) and, derived from the ontology, in the physical domain (XSD schema). The C2SIM Standard covers engineering guidelines (creating C2SIM models), data structure mechanisms (format and syntax for C2SIM models) and rules for execution (systems initialization and exchange of messages among the systems). C2SIM defines operations based on a logical (platform-independent) data model, which is specified in a compatible set of ontologies: a Core that consists of data classes expected to be used by all (or almost all) interoperating C2 and Simulation systems, a basic Standard Military Extension (SMX) consisting of classes expected to be used by all (or almost all) interoperating military simulations. It also defines procedures and ground rules for a group of extensions associated with various military domains (e.g., Land Operations and Autonomous Systems).

The C2SIM PDG was organized around development of these standards documents and associated guidance documents. The **C2SIM-Standard** provides, at a logical level (i.e., independent of how the data will be communicated), a core set of data elements common to most C2 and Simulation systems, combined with a standard way of adding to that core a collection of additional elements specific to a particular domain and/or context along with rules for using them in initialization and tasking-reporting messages. The standard is accompanied by two normative ontologies: the C2SIM Core and the SMX. The C2SIM Guideline document describes the process to serialize the logical data model classes of the ontology into a physical XML schema and also provides supporting information for its implementation.

3.5.3 Land Operation Extension

C2SIM Land Operations eXtension (LOX) will serve as an exemplar for other C2SIM extensions. It also will provide for continuity with maneuver warfare aspects of MSDL and C-BML that are not included in the LDM Core but are used by the international military simulation community.

The C2SIM Core is designed to provide a method to exchange information needed across multiple domains. The C2SIM Standard Military Extension (SMX) adds to the Core those classes, subclasses and properties that are expected to be needed by all military simulations. The Core is unencumbered by domain specific information, which is instead provided through specific extensions, starting with the SMX. This permits user to implement the smallest possible LDM consisting of the C2SIM Core and necessary extensions. The Land Operations Extension (LOX) uses the Core + SMX and adds the components necessary to exchange data concerning entities in scenarios with land focused operations. The LOX cannot operate on its own. It only operates when added to the C2SIM Core + SMX.

3.5.3.1 Design of Extension

Definition of an extension is expected to be undertaken by a collaborative group that wants to add a C2-simulation interoperation capability for a domain that does not have one. Such a group needs to have strong expertise in the domain of interest and to follow the procedures in this section. These procedures are intended to result in a family of compatible extension that can be combined as needed to deal simultaneously with whatever combination of domains their users require.

In developing the SMX and LOX extensions, the C2SIM PDG took advantage of 1) the availability of retired military SMEs to designate appropriate ontology classes and properties; and 2) the legacy of the MSDL and C-BML standards that had been developed previously to describe land warfare operations. The effective design of the Core enabled that process to be achieved in a very straight forward way, by adding to ontology classes as need (for example, in SMX adding to the Core class Entity subclass EntityDescriptor with properties such as hasAllegianceRelationship, hasCommunicationsNetwork and hasSide.

3.5.3.2 Schema Generation

Schema generation is achieved by processing the composite ontology (Core + SMX + LOX) through the Ontology-to-XSD transformation specified in the C2SIM Standard and implemented by the US Naval Postgraduate School in Extensible Stylesheet Language Transformations (XSLT). This process was used successfully, using the January 2019 ontology drafts, in C2SIM validation achieved in CWIX 2019 and the MSG-145 MiniEx in July 2019.

3.5.4 Autonomous System Extension

Autonomous Systems Extension (ASX) is an independent extension built upon the Core+SMX+LOX. The standard C2SIM core for orders, reports and initialization of scenarios, was enriched with new data elements peculiar to Autonomous Systems scenario. So, ASX was developed according to the information exchange requirements for the NATO M&S COE R2CD2 demonstrator on top of the core, the Standard Military Extension (SMX), which is part of the standard, and Land Operation Extension (LOX), which is considered the first extension developed directly by C2SIM PDG. The ASX can be seen as a subset of basement made by the C2SIM Standard, therefore the ASX XML schema maintains all the data elements from Core+SMX+LOX. An ASX message can contain standard structures together with new ones, moreover a standard C2SIM messages can be managed by systems which supports ASX.

3.5.4.1 Design of Extension

The methodology followed to design the extension is the standard two-step process, which can be followed for whichever C2SIM extension. These two steps are: building an ontology and generating an XML schema. Building the ASX ontology means to extend the objects and their properties, data and their properties, contained in the Core+SMX+LOX ontology. For this goal the Protégé software can be employed, as recommended by SISO C2SIM PDG. Their guidelines must be followed, avoiding repetitions and definitions of elements not peculiar to AS domain. In the following, some examples from ASX ontology are reported.

The ASX defines some subclasses to specify peculiar information to AS during tasking, reporting and initialization. For tasking it was necessary to define the "AutonomousSystemManeuverWarfareTask", a subclass of the "ManeuverWarfareTask" of the LOX, as shown in Figure 3-8. So, it inherits all the properties of the parent class and above, like all properties of a generic "Task". The "AutonomousSystemManeuverWarfareTask" adds information about the level of autonomy of the robots, because the order could be rejected if it asks for tasks too complex for the level of autonomy of the platform; sensors on-board of the autonomous platform; tactical attitude to assume to perform the task; tactical technical procedure to use to perform the task, if more than one is defined; flight formation for the UAV swarm if applicable. All this additional information is to be included as new object properties which refers to other defined classes and their occurrence, like if they are mandatory or not, their range of values, or if only one instance is acceptable or more than one.

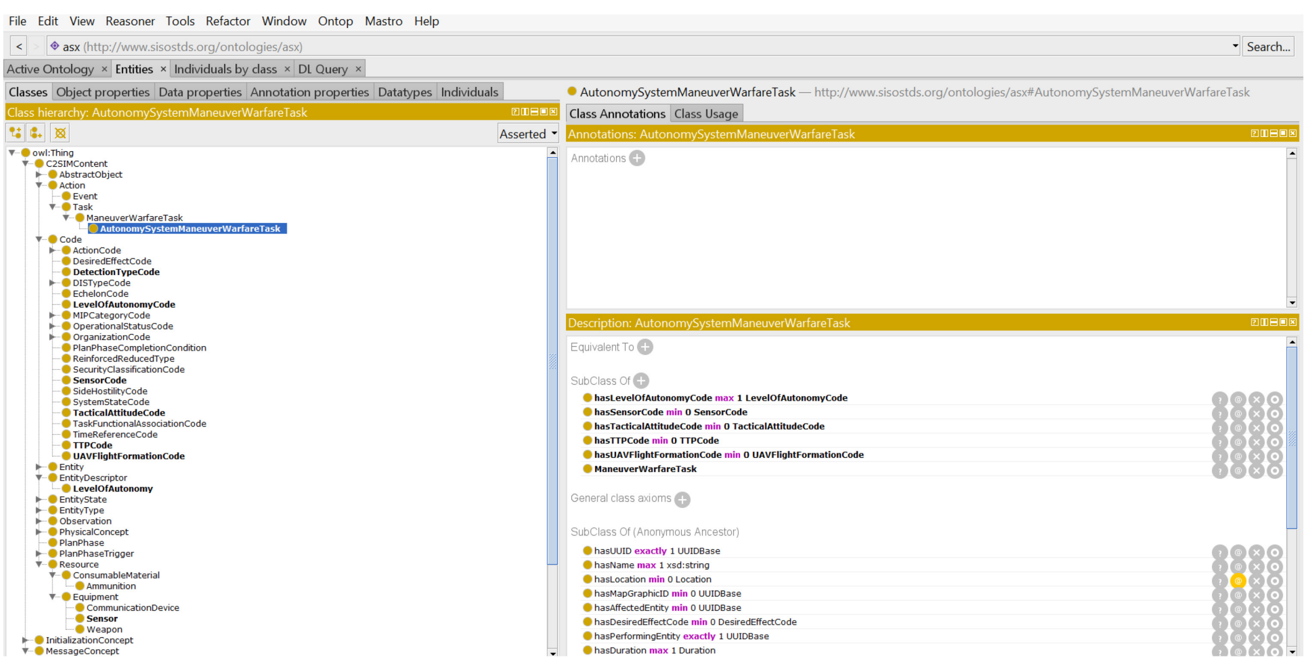

Figure 3-8: Snapshot of the Part of ASX Ontology's Taxonomy about Task Type.

For example, Figure 3-9 shows the case of the object property “hasLevelOfAutonomyCode”, which extends the “hasEntityDescriptor” and makes use of “LevelOfAutonomyCode”. As can be seen from figure, this is a property of both “AutonomousSystemManeuverWarfareTask” and “AutonomousSystemPositionReport-Content”.

Each class for a necessary new code is associated with its instances, which are the enumerates to define their values in the C2SIM messages. Figure 3-10 shows the case for “LevelOfAutonomyCode”; similar definitions are set for “SensorCode”, TacticalAttitudeCode”, “TTPCode”, “UAVFlightFormationCode”, “DetectionType-Code”.

For reporting, the classes “PositionReportContent” and “ObservationReportContent” were extended with subclasses to add information on the status of the AS in the case of position report and on the enemy for the observation report. For example, in a position report an AS informs about its battery or connectivity status, and about its current task and an eventual suggested task if this is compliant with its level of autonomy, as Figure 3-11 illustrates. This required to extend also the “EntityHealthStatus” class of the “PhysicalConcept”, but not its properties, since at the end of the process to generate the schema, only “hasHealthStatus” data property was extended to avoid duplications inside the ASX schema.

For the observation report, the class “HealthObservation” was generated from “Observation” parent class to include information about operational status and strength which were missing in this kind of report. Moreover, in the “AutonomousSystemObservatioReportContent” the “hasDetectionTypeCode” property was added to add information about the type of observation: if a discovery, or a detection or full identification of the enemy. Another class which was expanded is the “ActorEntity” of “Entity”, creating the subclass “Autonomous System”. Since an AS is an actor, meaning that it can perform an action/task, it cannot be treated as a simple platform. As already stated for other codes, also the “TaskNameCode” class needed the extension of enumerates (individuals in the ontology) to specify tasks which can be performed by AS.

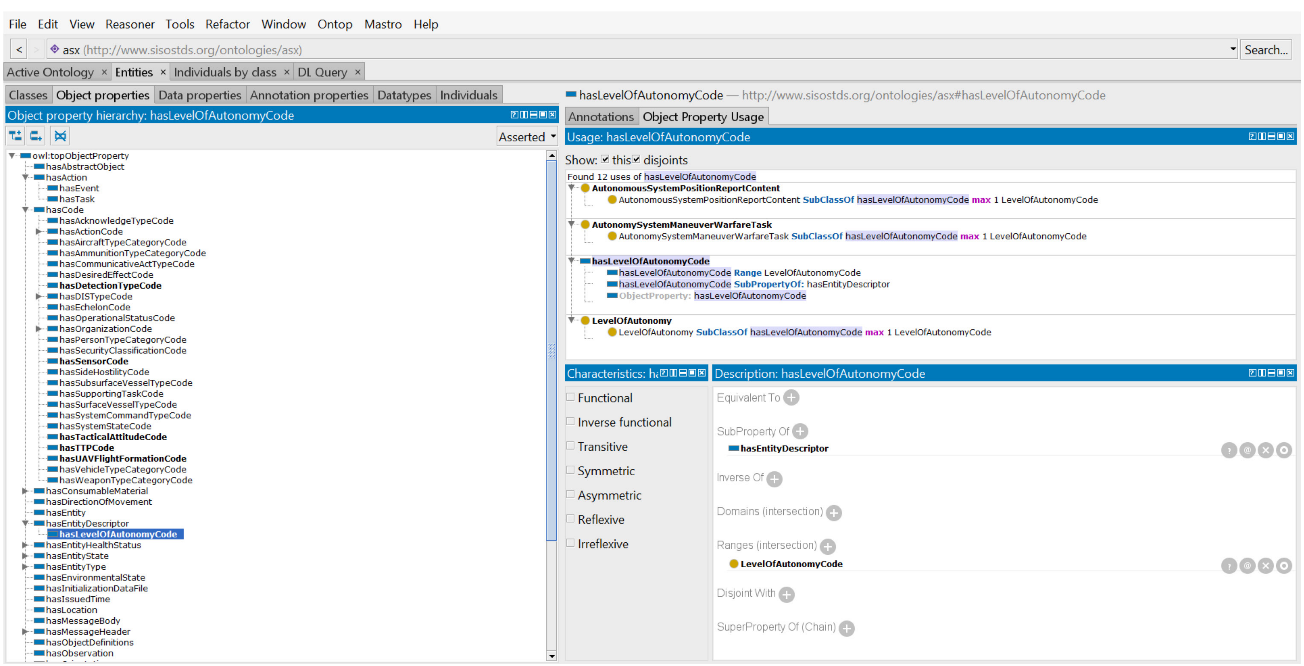

Figure 3-9: Snapshot of the Part of ASX Ontology’s Taxonomy about Object Properties.

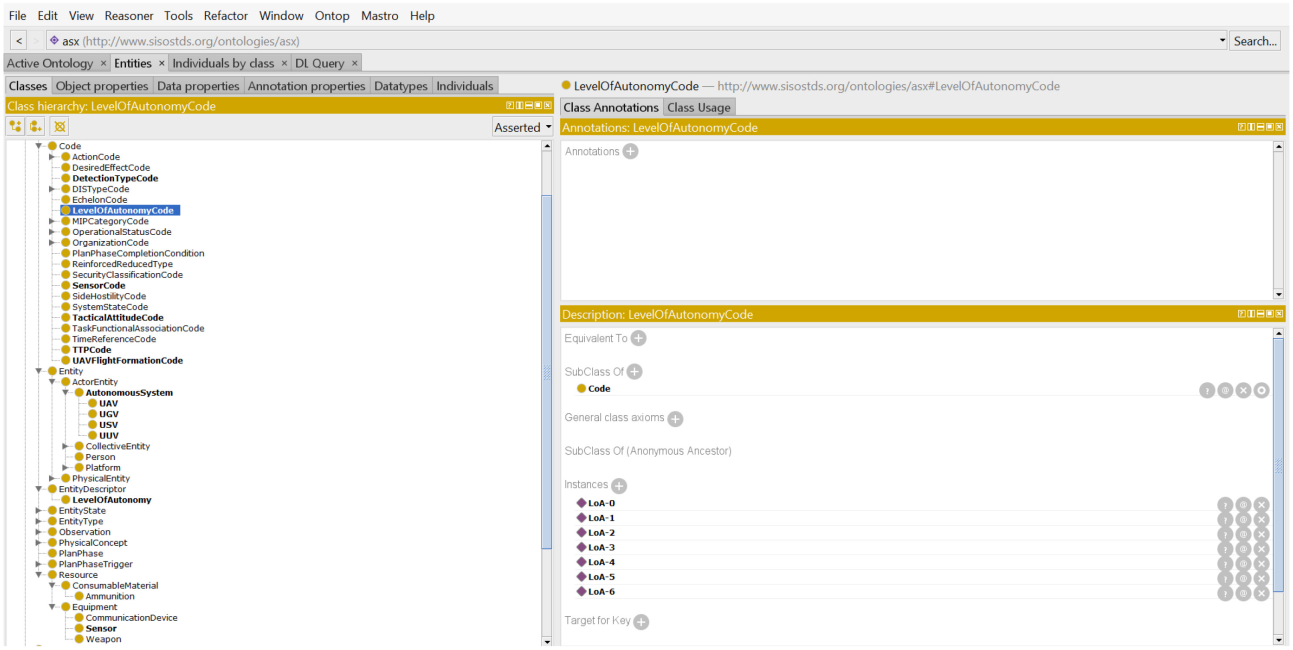

Figure 3-10: Snapshot of the Part of ASX Ontology's Taxonomy about Classes and Their Instances.

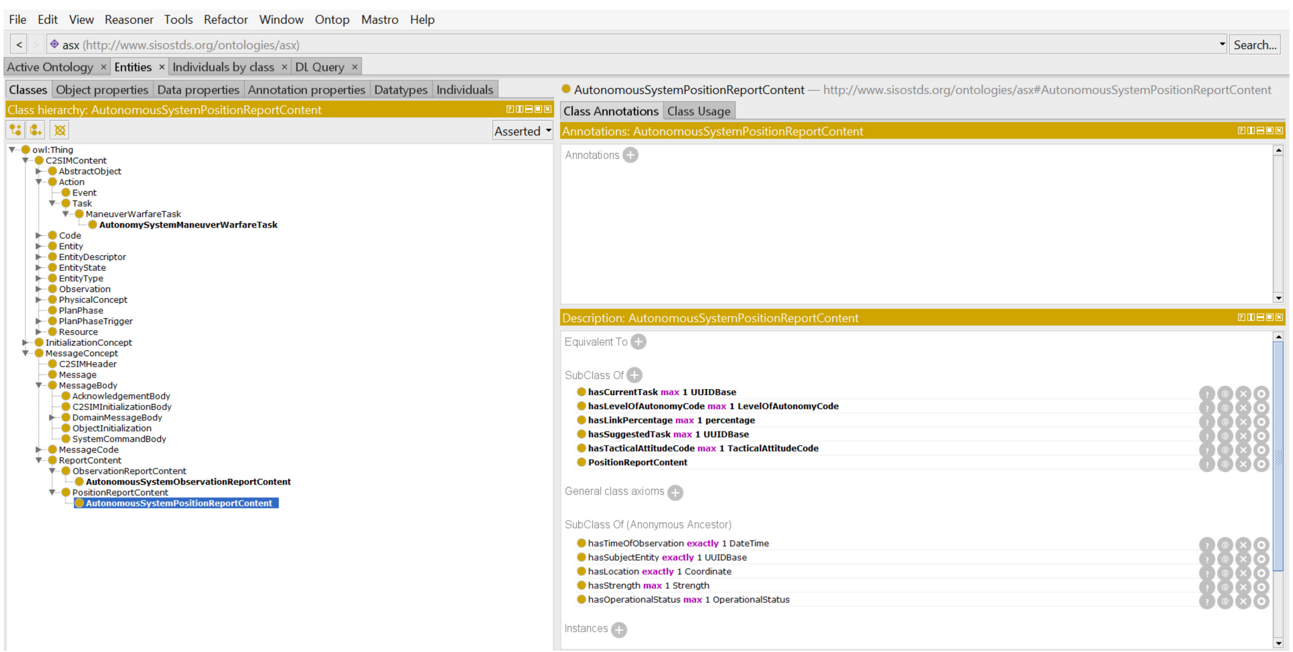

Figure 3-11: Snapshot of the Part of ASX Ontology's Taxonomy about Position Report Type.

3.5.4.2 Schema Generation

After building an ontology, the XML schema for an extension can be generated applying the standard SISO C2SIM XSLT. This is exactly what was done to derive the ASX XML schema from ASX ontology. Some refinements could be necessary to avoid useless duplications in the definitions of simple types, elements, complex types and model groups derived from the ontology. It is noteworthy that the described process for schema development is a continuous one: the ASX schema should automatically include any changes in the Core+SMX+LOX schema, and also eventual modifications in the ASX ontology, based on the modifications on the scenario requirements. Figure 3-12 shows, as example, part of the XML schema of “AutonomousSystemManeuverWarfareTask” with all new data elements which can be included in an order.

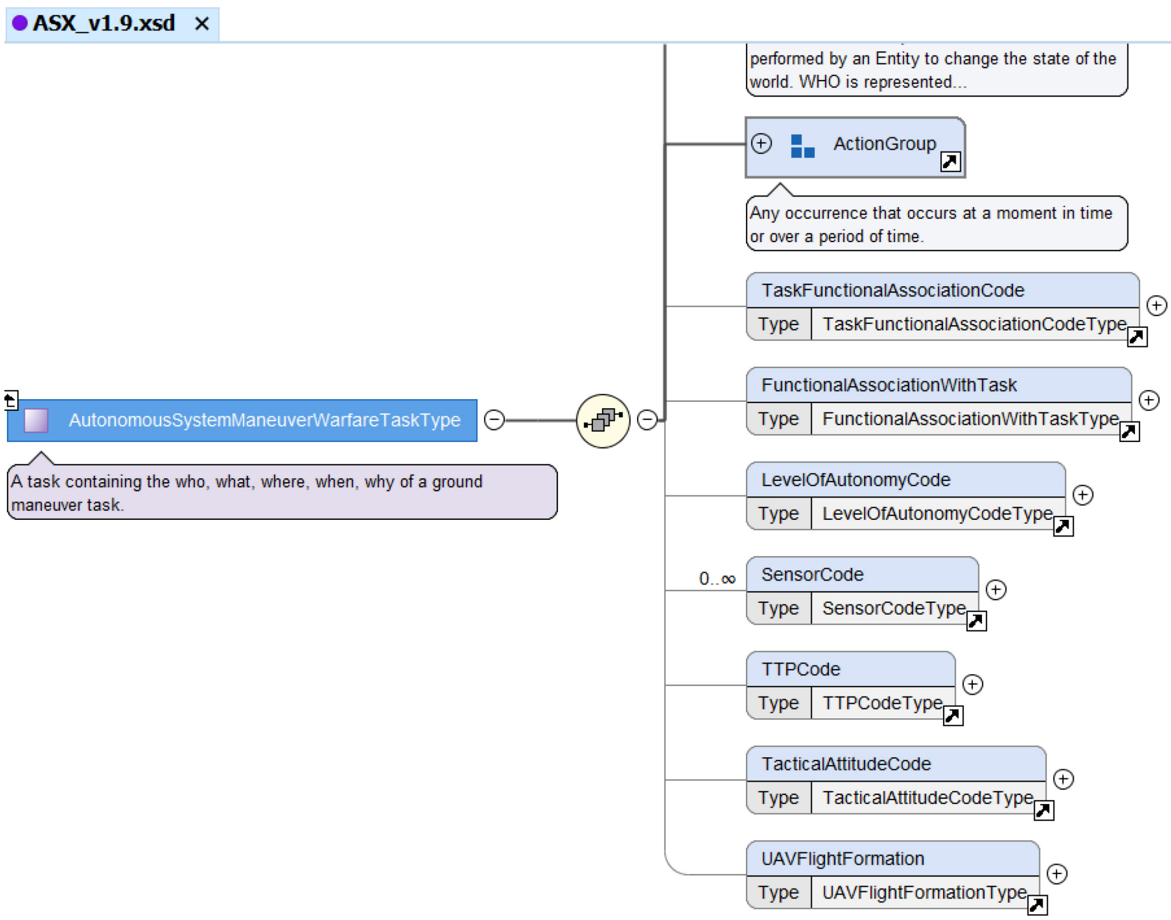

Figure 3-12: Snapshot of the Part of ASX XML Schema about Maneuver Tasks.

Figure 3-13 illustrates an example of a C2SIM ASX order which can be generated according to that schema. In this order three UAV are tasked to perform a reconnaissance of an area indicated by four points at its vertices. The order is directed to medium level of autonomy UAVs, which should perform the mission according to a TTP for a circular search, using two sensors in their payload: electro-optical and infrared. The UAV swarm has to move to the area of reconnaissance aware of the presence of enemy, so being in cover whenever possible, and adopting a linear formation with 12 meters of distance between each other.

C2SIM_ASX1_9_AirOrder_Medium LoA_Demo_Move.xml | C2SIM_ASX1_9_GroundOrder_Medium LoA_Move.xml


```xml
<?xml version="1.0" encoding="UTF-8"?>
<MessageBody xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://www.sisostds.org/schemas/C2SIM/1.1 ../Schema/C2SIM/C2SIM_ASX_v1_9.xsd"
 xmlns="http://www.sisostds.org/schemas/C2SIM/1.1"
 xmlns:c2s="http://www.sisostds.org/schemas/C2SIM/1.1">
    <DomainMessageBody>
        <OrderBody>
            <FromSender>9d9cfd24-3b64-11e9-b210-d663bd873d93</FromSender>
            <ToReceiver>953229ca-3b64-11e9-b210-d663bd873d93</ToReceiver>
            <Task>
                <AutonomousSystemManeuverWarfareTask>
                    <TaskNameCode>PATROL</TaskNameCode>
                    <c2s:StartTime>
                        <Name>H1.00</Name>
                        <IsoDateTime>2019-01-02T09:00:00Z</IsoDateTime>
                    </c2s:StartTime>
                    <PerformingEntity>00000000-0003-0001-0004-000000000002</PerformingEntity>
                    <PerformingEntity>00000000-0003-0001-0004-000000000003</PerformingEntity>
                    <PerformingEntity>00000000-0003-0001-0004-000000000004</PerformingEntity>
                    <!-- Delimiting points of the AOI for RECCE-->
                    <Location>
                        <Coordinate>
                            <GeodeticCoordinate>
                                <c2s:Latitude>40.863</c2s:Latitude>
                                <c2s:Longitude>14.285</c2s:Longitude>
                                <c2s:AltitudeMSL>20.0</c2s:AltitudeMSL>
                            </GeodeticCoordinate>
                        </Coordinate>
                    </Location>
                    <Location>
                        <Coordinate>
                            <GeodeticCoordinate>
                                <c2s:Latitude>40.862</c2s:Latitude>
                                <c2s:Longitude>14.313</c2s:Longitude>
                                <c2s:AltitudeMSL>20.0</c2s:AltitudeMSL>
                            </GeodeticCoordinate>
                        </Coordinate>
                    </Location>
                    <Location>
                        <Coordinate>
                            <GeodeticCoordinate>
                                <c2s:Latitude>40.846</c2s:Latitude>
                                <c2s:Longitude>14.311</c2s:Longitude>
                                <c2s:AltitudeMSL>20.0</c2s:AltitudeMSL>
                            </GeodeticCoordinate>
                        </Coordinate>
                    </Location>
                    <Location>
                        <Coordinate>
                            <GeodeticCoordinate>
                                <c2s:Latitude>40.847</c2s:Latitude>
                                <c2s:Longitude>14.282</c2s:Longitude>
                                <c2s:AltitudeMSL>20.0</c2s:AltitudeMSL>
                            </GeodeticCoordinate>
                        </Coordinate>
                    </Location>
                    <UUID>7ab53278-3b72-11e9-b210-d663bd873d93</UUID>
                    <Name>UAV_Recce</Name>
                    <LevelOfAutonomyCode>LoA-3</LevelOfAutonomyCode>
                    <SensorCode>EO</SensorCode>
                    <SensorCode>IR</SensorCode>
                    <TTPCode>CIR</TTPCode>
                    <TacticalAttitudeCode>AWARE</TacticalAttitudeCode>
                    <UAVFlightFormation>
                        <UAVFlightFormationCode>UAVColumn</UAVFlightFormationCode>
                        <UAVFlightFormationShift>12</UAVFlightFormationShift>
                    </UAVFlightFormation>
                </AutonomousSystemManeuverWarfareTask>
            </Task>
            <IssuedTime>
                <DateTime>
                    <IsoDateTime>2019-01-02T08:30:00Z</IsoDateTime>
                </DateTime>
            </IssuedTime>
            <OrderID>30bda688-3b6c-11e9-b210-d663bd873d23</OrderID>
        </OrderBody>
    </DomainMessageBody>
</MessageBody>
```


Figure 3-13: Snapshot of an ASX Order.

Figure 3-14 provides examples of position and observation reports.

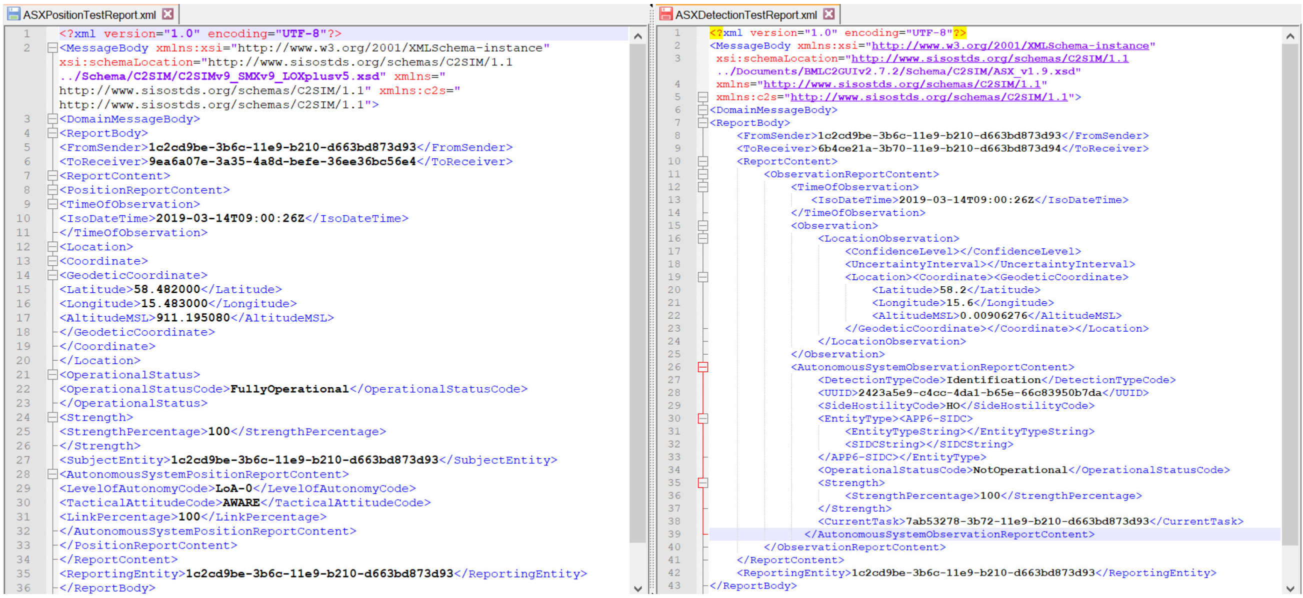

Figure 3-14: Snapshot of an ASX Report.

Below is a summary of the main lessons identified during the ASX schema generation:

- The ASX schema is a pure extension of the Core+SMX+LOX schema, so if C2SIM gateways support ASX in a coalition, they can manage pure C2SIM Core+SMX+LOX messages. Moreover, systems supporting ASX can receive and process pure C2SIM Standard messages.
- The XML schema generation process could be affected by useless duplications in simple types, elements, complex types and model groups, if in the definition of object properties and data properties in the ontology contains some redundancies.
- The described process could need to be repeated to expand further the ASX, depending on the missions and scenarios involving AS.
- The ASX is based on LOX, so on land domain. For the employment of AS in air and maritime domains with systems able to process operational messages peculiar to those domains, the ASX should be extended on top of eventual air and/or maritime extension.

3.5.5 Air Operation Extension

Air Operations stand out due to their dynamics as air-mobile forces are characterized by tactical mobility and speed. Communication follows this condition. In contrast to ground operations, air assets do not have to send e.g., position reports, but they are tracked automatically with position updates generated e.g., by an airborne radar picket system like AWACS. These sequences of positions are tracked for each aircraft and labelled with a track number. These track numbers can be used to communicate with an air-mobile force or a single aircraft. The communication in air operations includes the exchange of orders, requests and reports complying with the NATO standards for Tactical Data Link Exchange – Link 11 and Link 16 – which is described in STANAG 5516 and the US MIL-STD 6016. In the German-French Scenario for air operations (more details of which can be found in Annex C), the focus is on having generic messages for TDL networks, as suggested in Svensson et al. [16].

The air operation scenario used to create an air operation extension is based on a fictional operation executed by the Future Combat Air System to destroy hostile air defence (Destroy Enemy Air Defence / DEAD scenario). Own fighters, drone swarms, and the AWACS are connected by the TDL Network Link 16 and they exchange messages for situation awareness (tracks, own positions, targets) and for command and control. The Air Operation experimentation involves the simulation DirectCGF (DIGINEXT), the C2 surrogate C2LG (FKIE) and the ELLIPSE C2SIM server used to ensure the initialization and the exchanges between C2LG and DirectCGF. DirectCGF simulates all the entities on the battlefield. C2LG plays the command and control function of the AWACS on a subset of the entities. All other AWACS tasks, e.g., surveillance and the command and control of other entities, are simulated by DirectCGF.

3.5.5.1 Design of Extension

In this section, the result of the design of the TDL extension is first presented, with some examples. At the end of this section, the lessons learned are summarized.

The air operation extension was built to complement the C2SIM Core ontology and the Standard Military Extension (SMX). We followed the taxonomy from the core that subsumes classes under the superclasses “C2SIMContent”, “InitializationConcept”, and “MessageConcept”.

Three crucial examples for air operations are explained. One is “platform” that can include aircraft, but only “DISEntityType” and “APP6-SIDC” are needed to include instances for the scenario initialization data Figure 3-15.

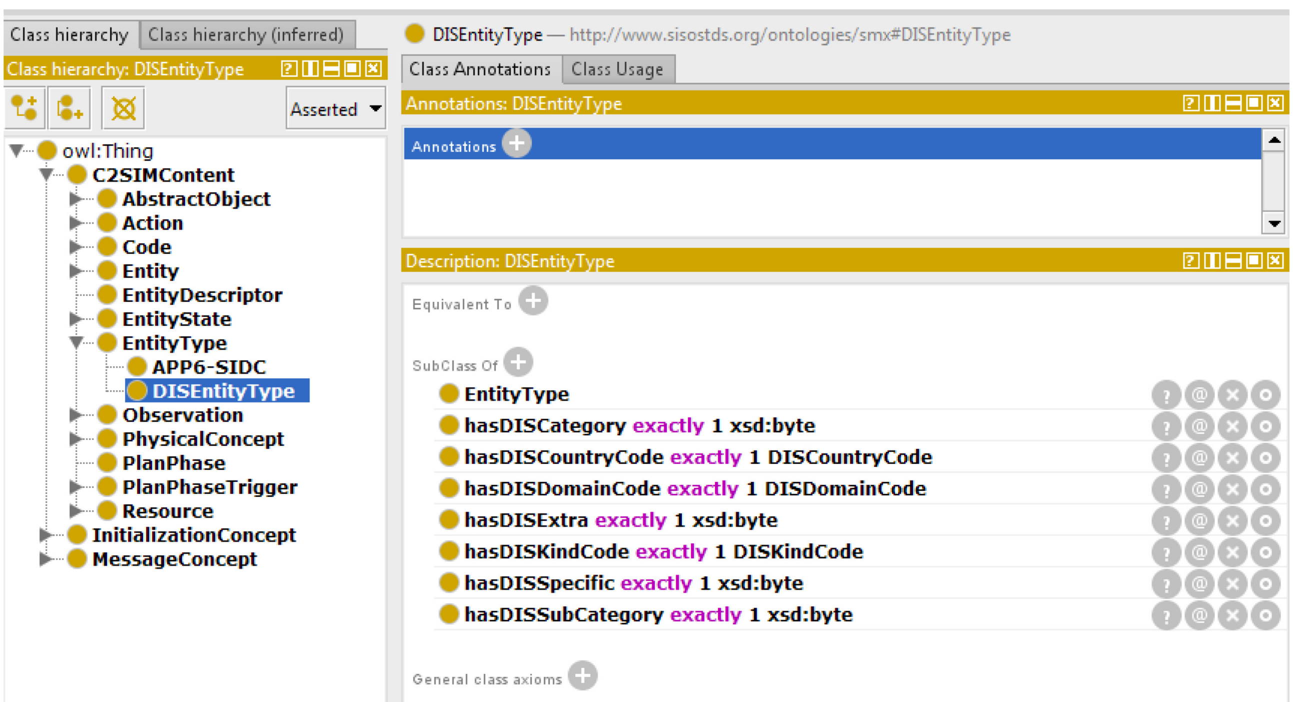

Figure 3-15: Snapshot of the Part of the Ontology’s Taxonomy That is About Entity Types.

With regard to communication, track numbers and the definition of participants of communications networks are inevitable in the air operation domain. The C2SIM Core ontology already has the class "CommunicationNetwork" and will be used to represent a Tactical Data Link network. In the initialization step "TDLNetworkParticipantDefinition" as subclass of "InitializationConcept" is used to refer to a network instance with the property restriction on "hasCommunicationNetworkUUID". This class is further defined by the properties "hasSubjectEntity" and "hasTDLTrackNumber" to assign an entity together with its track number to the network (Figure 3-16).

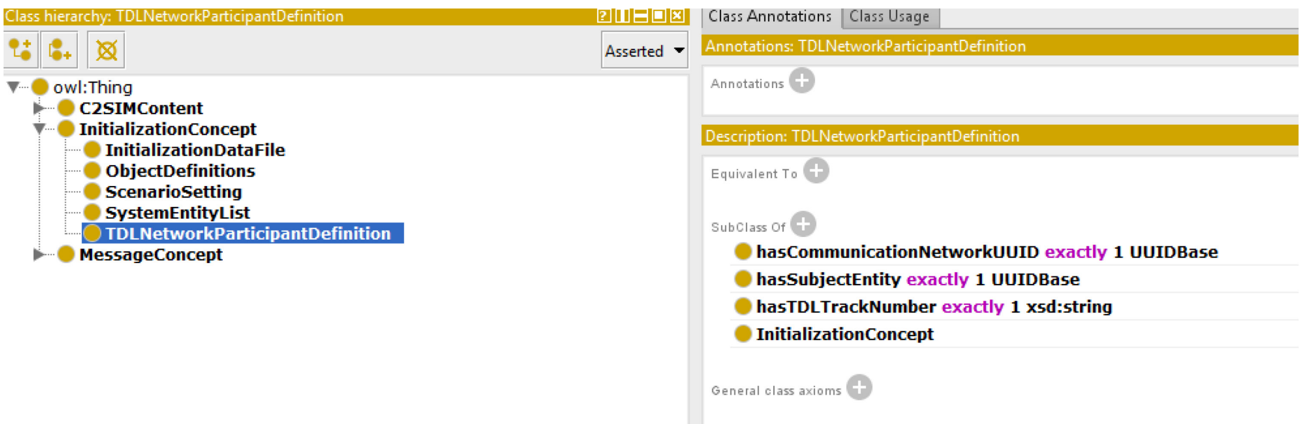

Figure 3-16: Snapshot of the Part of the Ontology's Taxonomy That Represents Knowledge to Be Applied During Initialization.

Within these communication networks, communication differs a lot from communication in other domains like land operations, e.g., sender and receiver often are not defined as individuals, but messages are broadcasted. In this respect, there were difficulties abiding by the structure of the Core ontology. As TDL includes specific information and extends the domain formerly covered by C-BML, we introduced the class "TDLMessageHeader" to declare on which network the message shall be broadcasted, with a new property restriction on hasCommunicationNetworkUUID. Specific classes have been introduced (in the TDL ontology extension) under the superclasses "ReportContent", "RequestBody", and "OrderBody" (of the Core ontology). As an example, Figure 3-17 shows that the TDL "PPLIReportContent" is subsumed under the predetermined "PositionReportContent".

PPLI is the abbreviation for "precise participant location and identification". It is a report from a sender about its own position, with additional information if necessary. The class for the body and thus for the content of a TDL PPLI ("TDLPPLIReportContent") is a subclass and thus a specific kind of "PositionReportContent" from the Core. For the extension, an artificial construction of "StandardPositionReportContent" as a complement to "TDLPPLIReportContent" has to be added. It results from an ontology principle that each class needs at least one sister class with at least one additional property. Otherwise, the class distinction would not make sense. "TDLPPLIReportContent" as its sister class inherits all properties of "PositionReportContent" including mandatory statements about the subject whose position is reported, of the responding location and of the time of observation (Figure 3-17). "TDLPPLIReportContent" has some properties that are specific and not inherited from "PositionReportContent" which are derived from the TDL PPLI's fields. For example, the TDL PPLI property "hasTDLEnvironment" points to a specific TDL environment. "TDL" is included to classes and properties that differ from the core classes and properties to indicate this. The properties that derive from the TDL PPLI include the subject's speed ("hasSpeed"), its direction of movement ("hasTDLDirectionOfMovement"), and the track number of its leader ("hasTDLLeaderTN") whereas its own track number is provided in the report's header. Some more properties are in the body. They can be used to provide more information about the sender, but they can be seen as superfluous since the subject's id and track number are given in the report's header. Nevertheless, the properties are included so that all fields of the TDL are covered. The superfluous properties are "isTDLControllingUnit", "hasTDLPlatformType", and "hasTDLVoiceCallSign". Another property is the already mentioned "hasTDLEnvironment" that has always the value "AIR" in our context.

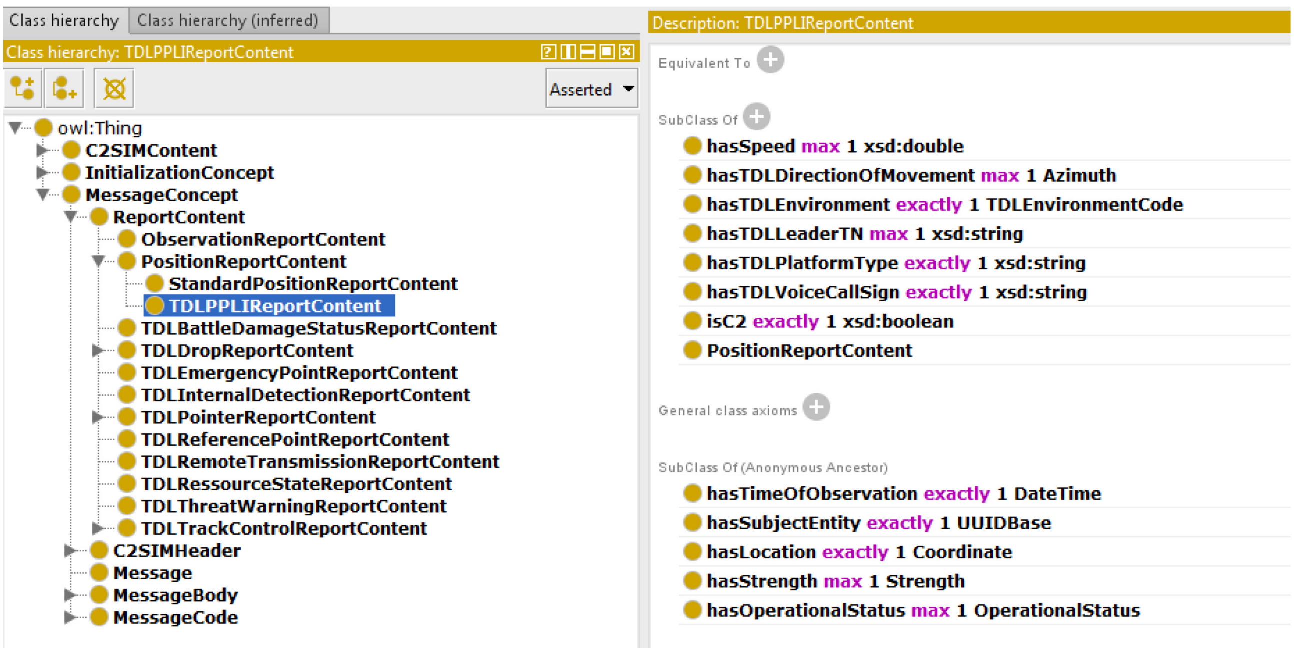

Figure 3-17: Snapshot of the Class "TDLPPLIReportContent".

A second example of a message in the air operation field is "Mission Assignment". In the C2SIM context, the class is semantically similar to task as part of an order, sent from a commander to the subordinated aircraft, with a single task containing the details of the "air mission". Therefore, "TDLMissionTask" will be modelled as a subclass of the C2SIM "Task" and be used in the C2SIM order message.

As depicted in Figure 3-18, "TDLMissionTask" is not directly a subclass of "Task", but the subclass "TDLTask" class is added in order to have a common root for all kind of tasks exchanged over TDL networks. The other TDL tasks are used for guidance commands (take a new direction, take a new altitude, speed, etc.), or to order to follow a flight plan (points with dates/times). "TDLMissionTask" inherits all properties of the C2SIM "Task" class, which includes a task UUID (property "hasUUID"), a reference to the taskee (property "hasPerformingEntity"), and the mission verb (property "hasTaskNameCode"). "TDLMissionTask" is additionally defined with new property restrictions. Due to its restrictions, an instance of "TDLMissionTask" would have a property "hasTDLTargetType" (to define the type of the target), and have maximum one property "hasTDLTargetTN" (to define a Track Number of the target), and have maximum one property "hasAttackAxis" (to define the direction of the aircraft before the aircraft launches its missiles), and so on. "TDLMissionTask" represents all TDL missions with verbs like, e.g., "investigate", "attack" (air to ground), "engage" (air to air) or "RTB" (returns to base). As mentioned before, "TDLMissionTask" inherits the property "hasTaskNameCode" and the corresponding range from its superclass "Task". However, the values that "TDLMissionTask" permits for TDL tasks constitute only a subset of all the values of "TaskNameCode". We took into consideration restricting the range of "hasTaskNameCode" for "TDLTask" to those codes that refer to a TDL task. However, this would lead in the generated schema to a double occupancy of that property resulting from inheritance, meaning "TDLMissionCode" would be defined by having a TaskNameCode exactly one TaskNameCode and exactly one TDLTaskCode. And this assertion would be wrong for the schema. Therefore, we did not restrict this property further in the ontology. But there are still discussions in the SISO PDG how to handle specifications of properties inherited from superclasses.

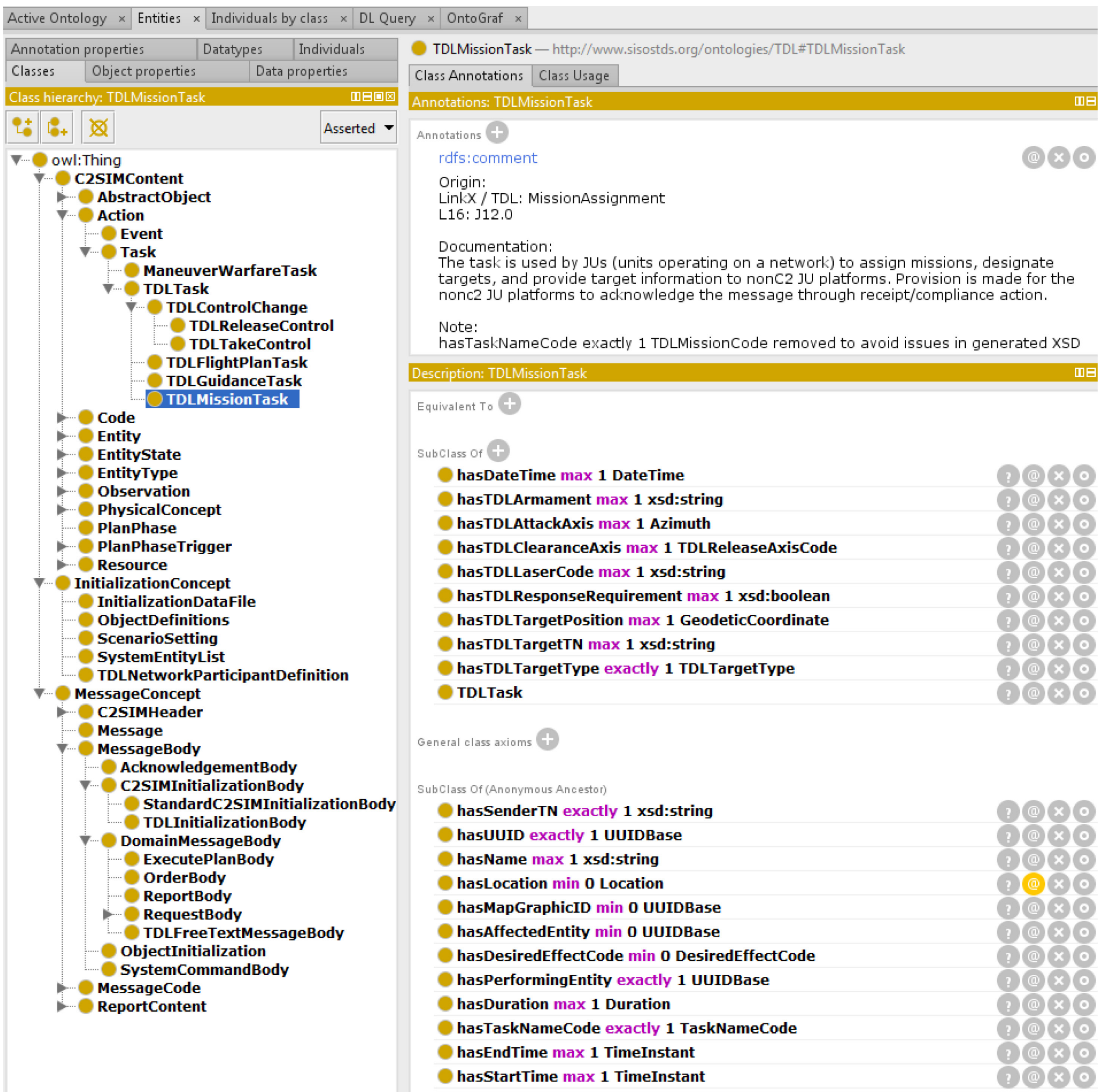

Figure 3-18: Snapshot of the Class "TDLMissionTask".

Below is a summary of the main lessons learned during the design of the TDL extension:

- Enumerations:

  We decided to model the enumeration values as individuals. This allows pointing directly to these specific enumeration values (the individuals) from different perspectives and classes. It is also possible to declare two individuals as being equivalent.

- Property ranges, restrictions and leaf classes:

  It is not possible to restrict the range of an inherited property restriction (example given above with "hasTaskNameCode"), because the schema generated out of the ontology will show two lines for the property. But there are still discussions in the SISO PDG how to handle specifications of properties inherited from superclasses.

  The range of the property restriction is not taken into account in the schema generation process. The extension developer shall take care that the range of the property definition are correctly defined, because they are used in the schema generation process.

3.5.5.2 Schema Generation

Blais et al. [15] describe how schemata are generated from ontological representations. This approach starts by merging the C2SIM Core with all required extensions, in this case the SMX extension and the described Air Operation extension. The schema is then generated automatically with an XSLT tool provided by SISO C2SIM PDG. As mentioned in previous Section 3.5.3.1, it raises some issues that have been solved by modifying the ontology, and by regenerating the schema.

Note: The C2SIM Standard describes the transformation restrictions and rules in its Annex B (normative). It does not contain the XSLT tool mentioned above. Other means of transformations (compliant with the Annex B of the C2SIM Standard) have not been implemented, and the compliance of the schemas obtained by different tools or means has not been tested.

The result is an extensive schema that covers all kinds of messages, those for initialization as well as those for the different operational exchanges during a military mission. In order to exchange information among the systems of a C2SIM coalition, the systems shall generate and be able to process XML messages compliant with the generated schema.

Figure 3-19 illustrates an XML file that is compliant with the generated schema.

Figure 3-20 shows a TDL mission order. During the transformation process, the prefixes "has" and "is" that are used for properties in the ontology are clipped so that for example the ontological property "hasPerformingEntity" is transformed into the tag "PerformingEntity".

The listing of the TDL mission order assigns the UUID "00000001-0000-0001-2000-000000000000" to the order, the verb "ATTACK" to the mission, the aircraft UUID "00000000-0000-0001-2000-000000000000" that will perform the mission, the track number "501" of the target, the type "AIR_DEFENSES" of the target, etc.

With the generated TDL schema, a simulation or CGF system can generate two kinds of ReportContent: the TDLPPLIReportContent for air entities, and the StandardPositionReportContent for other entities. Figure 3-21 shows an example of the structure of these two message bodies. Left side is an example for TDLPPLIReportContent. Right side is an example of StandardPositionReportContent. Both sides are compliant with the generated TDL schema.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Message xmlns="http://www.sisostds.org/schemas/C2SIM/1.1" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.sisostds.org/schemas/C2SIM/1.1 file:///C:/C2SIM/Comelec/Airbus/C2SIM_SMX_LOX_TDL.xsd">
	<C2SIMHeader>
		<StandardC2SIMHeader>
			<CommunicativeActTypeCode>Inform</CommunicativeActTypeCode>
			<MessageID>cd1d895f-ea3e-4858-906d-6abc93907a5d</MessageID>
			<Protocol>C2SIM</Protocol>
			<ProtocolVersion>1.1</ProtocolVersion>
			<SendingTime>2019-07-30T13:36:30:Z</SendingTime>
			<FromSendingSystem>C2LG</FromSendingSystem>
			<ToReceivingSystem>DirectCGF</ToReceivingSystem>
			<ConversationID>d10f9a43-e4ea-4edc-9ede-ebde7d5e1eb2</ConversationID>
		</StandardC2SIMHeader>
	</C2SIMHeader>
	<MessageBody>
		<DomainMessageBody>
			<OrderBody>
				<FromSender>00000000-0001-0001-1000-000000000000</FromSender>
				<ToReceiver>00000000-0000-0001-2000-000000000000</ToReceiver>
				<Task>
					<TDLTask>
						<TDLMissionTask>
							<TaskNameCode>ATTACK</TaskNameCode>
							<PerformingEntity>00000000-0000-0001-2000-000000000000</PerformingEntity>
							<UUID>cd1d895f-ea3e-4858-906d-6abc93907a5e</UUID>
							<Name>TDLMissionTask_1</Name>
							<TDLMissionType>ATTACK</TDLMissionType>
							<TDLTargetType>AIR_DEFENSES</TDLTargetType>
							<TDLAttackAxis>
								<Angle>90</Angle>
							</TDLAttackAxis>
							<TDLClearanceAxis>LEFT</TDLClearanceAxis>
							<TDLTargetPosition>
								<Latitude>50.397138</Latitude>
								<Longitude>9.862633</Longitude>
							</TDLTargetPosition>
							<TDLArmament>missiles</TDLArmament>
							<TDLTargetTN>501</TDLTargetTN>
						</TDLMissionTask>
					</TDLTask>
				</Task>
				<IssuedTime>
					<DateTime>
						<IsoDateTime>2019-07-30T13:36:30:Z</IsoDateTime>
					</DateTime>
				</IssuedTime>
				<OrderID>cd1d895f-ea3e-4858-906d-6abc93907a5f</OrderID>
			</OrderBody>
		</DomainMessageBody>
	</MessageBody>
</Message>
```

Figure 3-19: Mission Order as Completed XML Structure Conforming to the Generated Schema.

Figure 3-20: XML Examples of TDLPPLIReportContent vs. StandardPositionReportContent (TDL Extension).

Figure 3-21: XML Examples of StandardPositionReportContent (TDL Extension) vs. PositionReportContent (LOX Extension).

If a C2 System is "only" using the schema generated from core, SMX and LOX C2SIM ontologies, then the system expects to have a different content than the StandardPositionReportContent as shown before. Figure 3-22 illustrates the differences (StandardPositionReportContent with TDL extension on the left side, and PositionReportContent without TDL extension on the right side).

It simply shows that the XML content of the two messages is slightly different, but, however, "incompatible". So, if two systems developed for different extensions shall exchange messages defined in their common extensions, we have identified two ways to handle that kind of situation. First way is to have different versions of the C2SIM gateways, so that one version will manage in our case the LOX schema, and another version will manage the TDL schema. Second way is to manage the transformation between the two formats inside the C2SIM server. A third way is to avoid this situation, and to "upgrade" all the C2SIM gateways of all the systems in the coalition to the schema generated by merging of all the OWL extensions used in the experimentation (all systems will use the same schema).

Below is a summary of the main lessons learned during the schema generation, in addition to the lessons learned in the previous Section 3.5.3.1, because some are also linked to the schema generation process:

- XSD errors:

  The last issue identified with the C2SIM schema generation process is that the generated schema (XSD) is not always compliant with the W3C standard. Sometimes, there are some errors in the generated schema that can be seen when the schema is loaded in an editor checking the XSD syntax (Eclipse editor, XML Spy). These errors are all about a name (example "TDLEnvironmentCode") that cannot be resolved to a(n) 'element declaration' component within the XSD file. Currently, the solution is to add manually some instructions in the generated schema, such as:

  ```
  <xs:schema […]>
  <xs:element name="TDLEnvironmentCode" type="TDLEnvironmentCodeType"/>
  […]
  </xs:schema>
  ```

  The reasons for these errors have not been evaluated, yet. We assume that this could be due to some OWL definitions in the modelling of the Air Operation extension that have not been implemented yet in the generation process. There is work in progress on this issue at the SISO C2SIM PDG, too.

- Extension mechanism, and re-use of C2SIM systems across layers of extensions:

  All partners (MOD, industry, academic) may have concerns about re-using the previous development efforts made on their C2SIM systems or gateways and implement incrementally new capacities in the systems of gateways.

  We have figured out some constraints about the "re-use" with the current extension mechanism and identified how to manage these constraints today. It is by either implementing transformations in the C2SIM server, or by managing different versions of the C2SIM gateways for each system, or maybe by "upgrading" the C2SIM gateways of all the systems in the coalition to the schema generated with the merge of all the extensions used in the experiment.

3.5.6 Ground Combat Extension

For the Ground Combat Extension, we used for our validation process a scenario-based on the future German Main Ground Combat System (MGCS). The scenario has been implemented in KORA; the orders and reports to be generated between the C2 System and the simulation system are specified through our extension based on the use of a German-French modified process.

The scenario used is at battalion level illustrating a ground-based manned-unmanned teaming concept, and contains as a series of tasks like:

- Reconnaissance of battlespace by a swarm of Mini-UAVs,
- Detection of enemy troops and engagement by Joint Fire Support,
- Engagement of enemy Mini-UAV by High Energy Laser,
- Engagement of approaching enemy By NLOS and Hyper Velocity Missiles,
- Blocking the enemy by Next Generation Scatterable Mines, and
- Destroying the enemy by combined forces.

The use of such extensive scenario/vignettes allows the testing of different sophisticated orders and reports between the simulation KORA and the C2 System, where the FKIE C2LG is playing the role for the C2 System for testing purpose.

3.5.6.1 Design of Extension

Unlike the C2SIM use cases for autonomous systems and air operations, ground combat differs in that it is not distinct from the other domains but can rather be seen as land operations with the employment of autonomous systems. As a Land Operation Extension (LOX) has already been proposed and an Autonomous System Extension (ASX) will be in the near future [17] our design of extension on the one hand sticks to the design of C2SIM Core, the Standard Military Extension (SMX) and the Land Operation Extension (LOX) bearing in mind that it also should be compliant with AOX. As all extensions had been work in progress while we extended our extensions for our purposes, it might be superfluous in the end when the UAV extension by [17] will be considered as a “standard” extension.

Therefore, the work done by FKIE and IABG is a preliminary extension for the German-French experimentation and later will offer discussions for the other two extensions.

Just as in the other extension processes, we also used the process proposed by the SISO-C2SIM-PDG, we used a merged version of the C2SIM Core ontology, the Standard Military Extension (SMX) and the Land Operation Extension (LOX) for further expansions of the ontology.

The process was two-fold, enabling initialization and tasking and reporting. For initialization, no adjustments were needed. For tasking and reporting, some complements were added.

A major focus was to enable tasking and reporting due to our Ground Combat Scenario. We used the “ManeuverWarfareTask” class from the LOX extension for tasking of our units. As the properties delivered by the C2Sim Core for “ManeuverWarfareTask”, e.g., “hasPerformingEntity” requires the simple datatype “UUIDBase” instead of connecting performing entity with “Unit” class, there is no connection between the performing entity and the “Unit” class properties. In this context, no inheritance takes place. Either way, we adjusted the “Unit” class as it could be used in the future for tasking, if we would refer instances of the type “UUIDBase” also to the “Unit” class.

To further define units, we needed to add a “CoordinateLeftBoundary” and a “CoordinateRightBoundary” which has been demanded by the simulation system KORA to restrict the units’ positions. They are linked via the datatype properties “hasLeftBoundary” and “hasRightBoundary” as shown in Figure 3-22.

As we also needed to task unmanned systems like UAVs, we added a sister class to “ManeuverWarfareTask”, namely the “UAVTask” as part of an order (see Figure 3-23). For these kinds of tasks, we had to add new “TaskNameCodes”, such as “March”, “HLDDEF(HoldDefensive)” and “Fire”.

Furthermore, we expanded the platform class to differentiate between “FlyingObject” like UAV in this scenario and tank as Vehicle (see Figure 3-24).

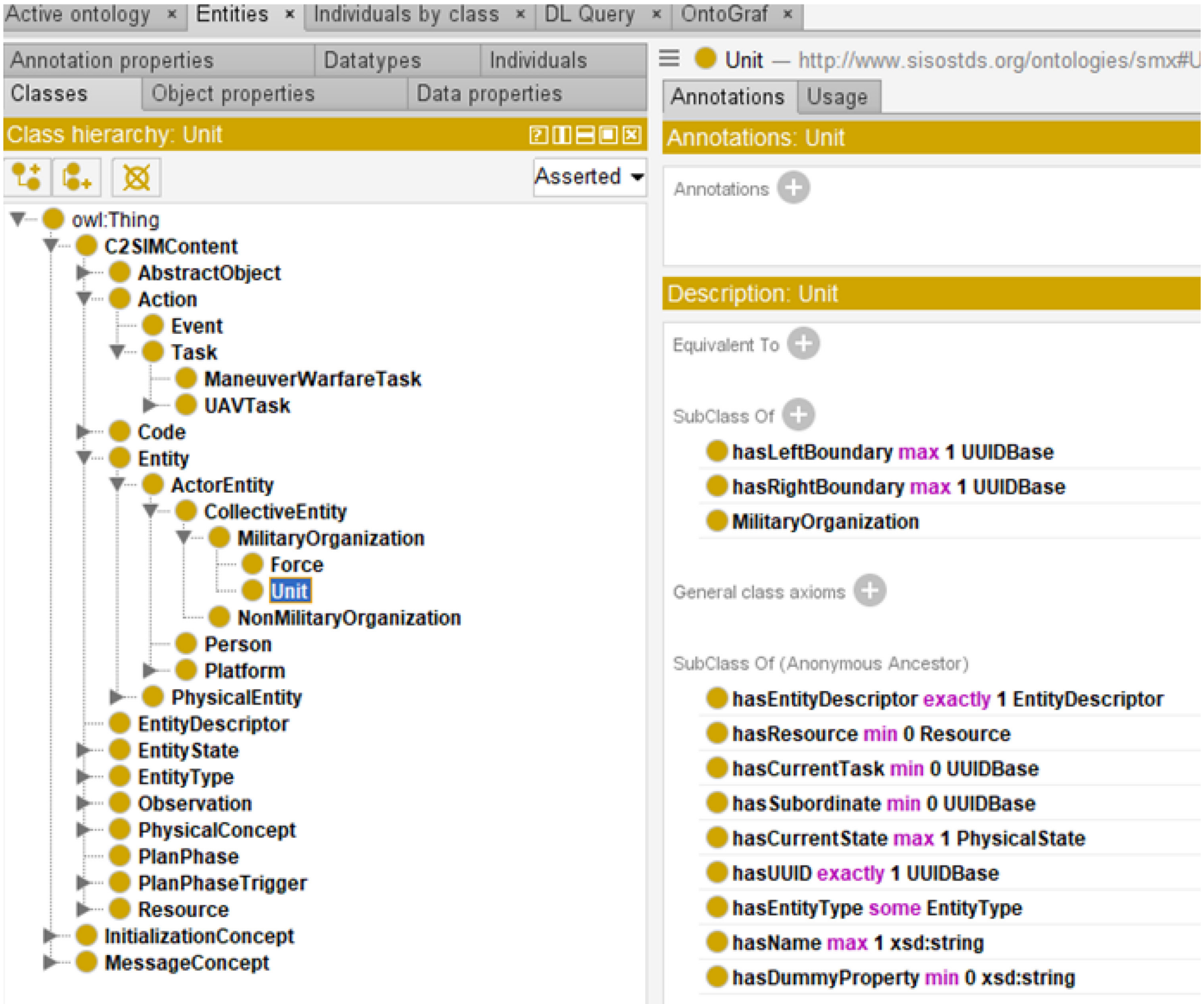

Figure 3-22: Boundaries "CoordinateLeftBoundary" and "CoordinateRightBoundary".

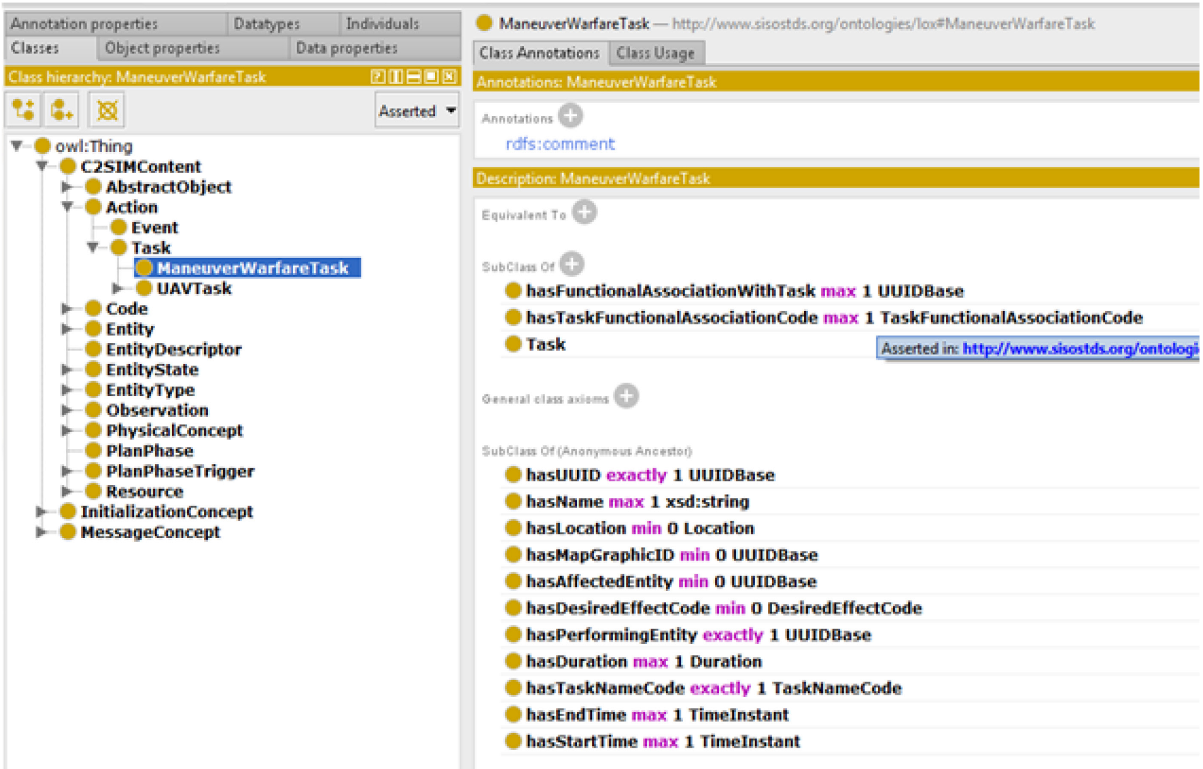

Figure 3-23: Maneuver Warfare vs UAV Task.

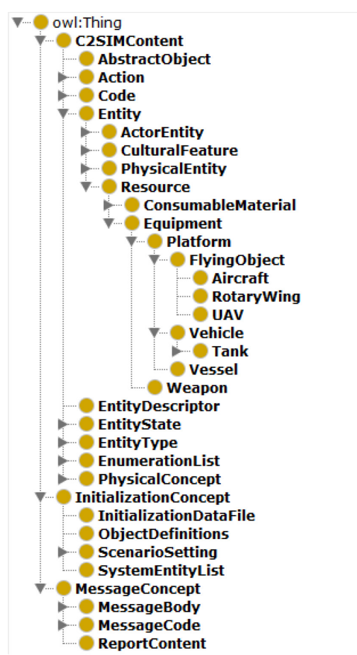

Figure 3-24: Different Platform Types in Ontology.

3.5.6.2 Schema Generation

The schema in the Ground Combat Scenario is generated automatically with an XSLT tool provided by SISO – PDG explained in Blais et. al. [15]. On one hand, an initialization file provided by the ontology is used and filled manually. On the other hand, messages that are extracted and implemented into KORA and C2LG. The schema is shown in Figure 3-25. Figure 3-25 shows an attack order that has been provided by the Maneuver Warfare Task. Therefore, no differences to the Core model occurred.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<Message xmlns="http://www.sisostds.org/schemas/C2SIM/1.1" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://www.sisostds.org/schemas/
C2SIM/1.1 file:///C:/C2SIM/Comelec/IterativeFkieIabgExtension/C2SIM_SMX_LOX_Version3.xsd">
    <C2SIMHeader>
        <CommunicativeActTypeCode>Inform</CommunicativeActTypeCode>
        <ConversationID>cdfd3f6b-9f03-44cc-9707-4318b6dab463</ConversationID>
        <MessageID>91b46f3c-d679-48f6-88e7-c7d147ae38b0</MessageID>
        <Protocol>C2SIM</Protocol>
        <ProtocolVersion>9.6</ProtocolVersion>
        <SendingTime>2019-08-01T06:00:00:Z</SendingTime>
        <FromSendingSystem>BMLWebGui</FromSendingSystem>
        <ToReceivingSystem>ALL</ToReceivingSystem>
    </C2SIMHeader>
    <MessageBody>
        <DomainMessageBody>
            <OrderBody>
                <FromSender>00000000-0001-0037-0000-000000000000</FromSender>
                <ToReceiver>00000000-0001-0342-2300-000000000000</ToReceiver>
                <Task>
                    <ManeuverWarfareTask>
                        <DesiredEffectCode>IDNT</DesiredEffectCode>
                        <TaskNameCode>ATTACK</TaskNameCode>
                        <StartTime>
                            <IsoDateTime>2019-08-20T06:00:00:Z</IsoDateTime>
                        </StartTime>
                        <AffectedEntity>00000000-0002-0001-0000-000000000000</AffectedEntity>
                        <PerformingEntity>00000000-0001-0342-2300-000000000000</PerformingEntity>
                        <Location>
                            <Coordinate>
                                <GeodeticCoordinate>
                                    <Latitude>50.907482</Latitude>
                                    <Longitude>11.020508</Longitude>
                                </GeodeticCoordinate>
                            </Coordinate>
                        </Location>
                        <UUID>6722b597-a588-409e-bfc9-c1efa5f3a07a</UUID>
                        <Name>AttackEnemy</Name>
                    </ManeuverWarfareTask>
                </Task>
                <IssuedTime>
                    <DateTime>
                        <IsoDateTime>2019-08-01T06:00:00:Z</IsoDateTime>
                    </DateTime>
                </IssuedTime>
                <OrderID>9e0e261c-3094-44a8-877c-43e410c5f263</OrderID>
            </OrderBody>
        </DomainMessageBody>
    </MessageBody>
</Message>
```


Figure 3-25: Specific Attack Schema.

3.6 C2SIM AS A SERVICE

Modelling and Simulation as a Service (MSaaS) is a new approach being explored by the STO NMSG 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" [18].

As described in the C2SIM Integration Platform (IP) Reference Architecture (RA) (Annex A) "C2SIM as a Service" is provided defining Architecture Building Blocks (ABBs) using both the NATO C3 Taxonomy and the MSaaS Reference Architecture from NATO MSG-136. Examples of ABBs for "C2SIM as a Service" are: Message-Oriented Middleware Service, functionality to support the exchange of messages between data producers and consumers, independent of the message format and content; 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 the Open Cloud Environment ApplicatioN (OCEAN) developed by NATO Modelling and Simulation Center of Excellence (M&S COE) in collaboration with the Leonardo company. This MSaaS cloud-based testbed prototype 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. The system architecture involves the use of a hybrid cloud where the user can mix use of physical machines, virtual machines and containers by means of a Platform as a Service solution based on OpenStack installed inside a VMware cluster.

3.7 NATO STANDARDIZATION

The testing of the draft SISO C2SIM Standard by MSG-145 helped support the case for its approval as a SISO standard. The adoption of the standard by NATO through a Standardization Agreement (STANAG) then allows NATO nations to specify C2SIM interoperability capability for any procurement programs. The STANAG production process is outlined in the following steps:

1) MSG-145 drafts a Standardization Proposal (SP) and the associated Standardization Inquiry (SI) and submit to MSCO;
2) MSCO shall then distribute the SP and the associated SI form, through official channels, for staffing by Allies (including Partners if applicable) and relevant NATO bodies;
3) If responses to the SI indicate that the need for such standardization proposal is confirmed by Allies, MSG-145 shall develop a draft Standardization Task (ST);
4) NMSG approves the ST; and
5) MSG-145 drafts the STANAG.

The STANAG development process is described fully in the NATO Standardization Office's (NSO) Allied Administrative Publication (AAP) AAP-03 [19]. The NATO Modelling and Simulation Standards Sub-group (MS3) has been identified as the sponsor for the C2SIM STANAG.

Chapter 4 – EXPERIMENTS, WORKSHOPS AND CONFERENCES

The experimentation program represents an important part of the MSG-145 program of work. The experimentation program is comprised of a series of events, primarily demonstrations. These events have several purposes:

- They confirm the operational relevance and measure the benefits of existing C2SIM Interoperability approaches;
- They identify limitations and areas of improvements of existing technologies;
- They help to inform the broader community concerning the state-of-the-art in C2SIM Interoperability; and
- Perhaps the most important of all, the lessons learned from these events contribute to the elaboration of a set of recommendations for standardization bodies that are developing C2SIM Interoperability standards.

This chapter summarizes the experimentation events conducted by the MSG-145 Technical Activity. It also summarizes the various communication and education events that were organized by and/or included significant participation by MSG-145 members. In addition to the events described below, MSG-145 organized several internal workshops, including workshops on: Applied Ontology for C2SIM Interoperation; and a multi-domain C2SIM Interoperability Workshop. The following sections highlight the events that were held in public forums. Section 8.2 lists a number of papers, presentations, etc. produced by members of the group during its existence.

4.1 CWIX

Starting in 2017 MSG-145 has participated in CWIX in order to test the interoperability of C2SIM implementations while also providing visibility in the NATO technology community. The Coalition Warrior Interoperability Exercise, or CWIX, is the premier NATO interoperability event. It provides an opportunity for the nations to test existing and future standards in a joint, secure environment. Thus, CWIX participation was an important arena for MSG-145 for testing the C2SIM standard together with the C2 community.

4.1.1 CWIX 2017

In 2017 there was not a C2SIM XML schema available, so the C2SIM Sandbox was used with the legacy schemata Integrated Battle Management Language 2009 (IBML09) and Military Scenario Definition Language (MSDL), enabled by the backwards compatibility of the Reference Implementation C2SIM Server in the Sandbox. The Internet VPN associated with the Sandbox supported participation of the UK Dstl with simulation JSAF, GMU C4I and Cyber Center with simulation VR-Forces, and BMLC2GUI[1] acting as surrogate C2 system. The CWIX testing methodology was followed for a basic interoperability test, which was passed by the test configuration with no exceptions.

4.1.2 CWIX 2018

For CWIX 2018 an initial prototype of C2SIM was available. It was implemented by DEU Company IABG in simulation KORA, USA GMU C4I and Cyber Center interface for VT MÄK simulation VR-Forces, and the

[1] Now known as the GMU C2SIMGUI.

NOR C2 system NORCCIS with FFI SWAP web browser interface. The secure Combined Federated Battle Laboratories Network (CFBLNet) was used to interconnect FFI and the CWIX main site at NATO Joint Forces Training Center (JFTC) Bydgoszcz, Poland. Original plans called for participation of US Army Test and Evaluation Command (ATEC) Huntsville AL, Dstl Portsdown West GBR, and M&S COE Rome ITA but those sites were not able to achieve secure operability by the time of the CWIX testing. Instead, VR-Forces were run at JFTC and a logfile from pretesting was used to introduce expected network transactions from JSAF in legacy format IBML09. These joined KORA, which had been planned to operate at JFTC, and interoperated over CFBLNet with NORCCIS/SWAP. The CWIX testing methodology was followed for a basic interoperability test, which was passed by the test configuration with the constraint that true interoperation with JSAF was not possible.

4.1.3 CWIX 2019

In January 2019 a draft version of the C2SIM standard became available; it was implemented between February and May 2019 by eight systems. This demonstrated the priority given to the project and technical acumen of the MSG-145 national teams and also the straightforward nature of C2SIM implementation:

- VT MÄK VR-Forces C2SIM Sandbox version from USA GMU C4I and Cyber Center operated by the US Naval Postgraduate School (NPS) Monterey CA;
- VT MÄK VR-Forces from Antycip Simulation in ASX prototype operated by M&S COE in ITA;
- SWORD from FRA company MASA Group, in an ASX prototype operated by M&S COE in ITA;
- US Army simulation OneSAF, operated by ATEC Huntsville AL;
- DEU simulation KORA from iABG, operated at JFTC by iABG;
- US Army Mission Command (C2) selected system SitaWare from Systematic Software, situational awareness capability (but not Order interface) as interfaced by GMU C4I and Cyber Center;
- C2SIMGUI C2SIM editor from GMU C2I and Cyber Center as surrogate C2, operated at all sites and used as system monitor at JFTC; and
- The Reference Implementation C2SIM Server from GMU C4I and Cyber Center, run at both M&S COE Rome ITA and GMU Fairfax VA USA, with the two instances on separate VPNs and linked by Back-to-Back (B2B) clients. This arrangement was necessary because USA policy would not allow US Army OneSAF and SitaWare to run on a network shared with NATO partners; a firewall permitted only the C2SIM network ports to exchange data via the B2B clients.

In addition, GBR Dstl continued to run simulation JSAF using legacy XML schema IBML09, via the server's backward compatible interface.

While operating over the secure CFBLNet in 2018 gave C2SIM testing more visibility to other CWIX participants, the overhead involved in preparation for secure network operation would have precluded the testing scope achieved by MSG-145 in CWIX 2019. Instead, Internet VPNs were used and all data was unclassified and publicly releasable. The network architecture used in CWIX 2019 was similar to that shown below in Figure 4-1 for the Mini Exercise discussed in the next section (New Zealand DTA participated in the MiniEx but not in CWIX 2019). The commercial Internet conferencing system Zoom was used to communicate among the various Internet sites involved.

At the end of CWIX 2019 testing, eleven of the twelve Test Cases in the CWIX testing methodology were reported with full success. The twelfth case was a limited success; the schema translation feature failed, causing an incorrect map icon to appear, however the human operator could still see the icon's location accurately and compensate mentally. This server error was corrected before the experimentation phase described next.

4.2 MINI EXERCISE

MSG-145 conducted additional C2SIM validation in 2019. While CWIX interoperability testing was an important step, its success indicated only that the C2SIM-interfaces systems were able to exchange information effectively. To show validity for the purpose of military operations, MSG conducted a distributed mission planning exercise called "MiniEx" for a two day period. This was similar in nature to the exercise conducted in 2013 at Fort Leavenworth, KS as the final demonstration of MSG-085 [1], with the exception that it was actually distributed among the six sites shown in Figure 4-1, whereas the 2013 event had only two Internet sites and only software, not role-players, at either of them. The scenario used involved a fictional nation "Bogaland" that has requested NATO assistance in dealing with terrorist paramilitary forces arriving from a hostile neighboring nation. Further details of this are given in Annex B. An additional site at Auckland NZL Defence Technology Agency (DTA) using C2SIM-interfaced simulation VBS3 and surrogate C2 system C2SIMGUI was added for the MiniEx. Two Zoom channels were used: in addition to technical coordination (as in CWIX 2019), a voice and text channel was needed for exercise participant communications.

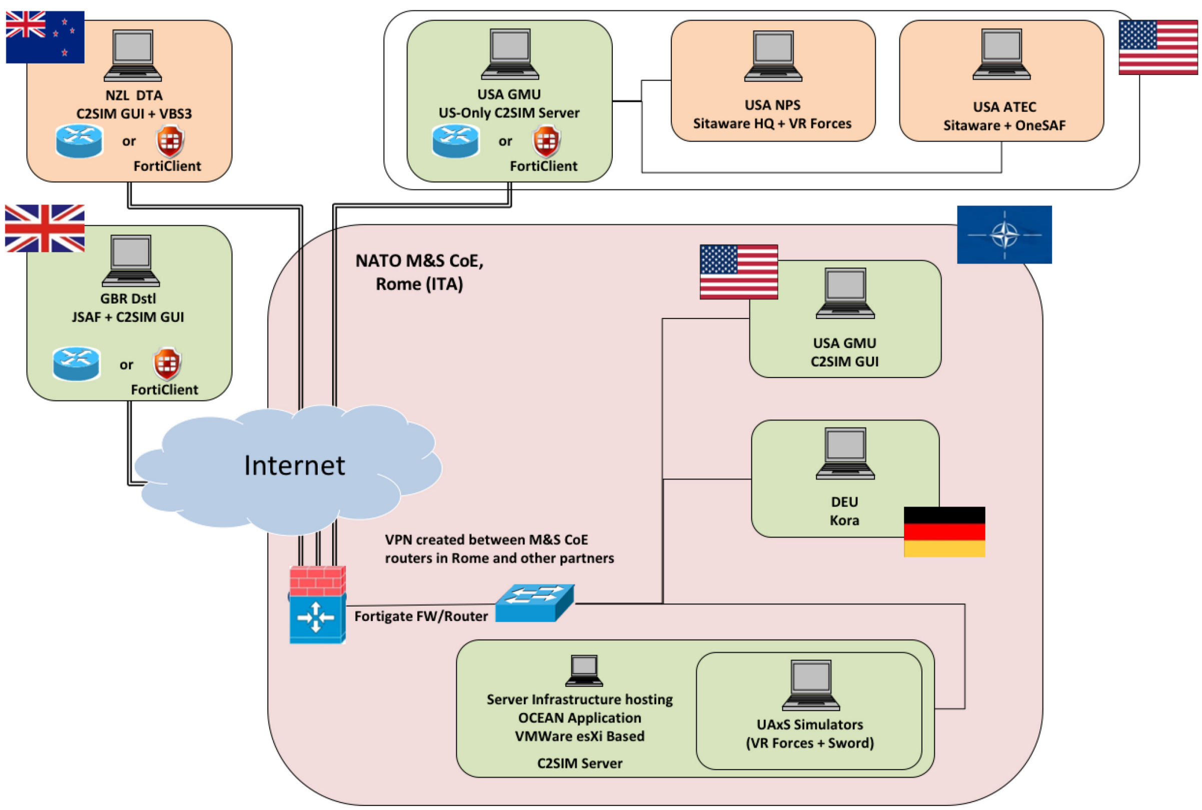

Figure 4-1: MSG-145 Network Architecture for MiniEX 2019.

The problem faced by the friendly coalition is to find and suppress the Red force, so the MiniEx was not conducted with a thinking enemy; the Red forces were largely stationary and only two orders were required to be given to the Red objects. A drawback in the experimentation was that the originally planned Distributed Interactive Simulation (DIS) interconnection turned out shortly before the MiniEx to not be possible due to VPN limitations, so simulators were not aware of each other's simulated objects. Therefore, to provide for a reasonable level of Blue/Red interaction, the Red objects which were configured in the same simulations as the Blue force but under orders from the exercise observer C2SIMGUI station.

Two complete executions of the distributed mission planning exercise were conducted. In the second, CyberEW effects were imposed by the servers as described in the USA Cyber Use Case above and detected by the MiniEx participants. The consensus of all participants in the MiniEx was that C2SIM is functional and not difficult to implement, so it was ready to move forward to balloting after ontology issues discovered during the MSG-145 C2SIM validation process were resolved.

4.3 NATO CA^{2}X^2 FORUM

As part of its objective to educate the community of practice, MSG-145 has provided a status briefing and demonstration at the annual NATO Computer Aided Analysis, Exercise, Experimentation (CA^{2}X^2) Forum organized by the M&S COE.

In 2017 GBR Dstl and USA GMU C4I and Cyber Center provided a tutorial with elements drawn from the MSG-141 C2SIM Lecture Series plus a demonstration using capabilities organized for the CWIX 2017 testing.

In 2018 GBR Thales-UK provided a briefing on the emerging C2SIM standard by one of their people who is a Co-Chair of the SISO C2SIM Product Development Group, accompanied by a recording that captured playback of a server log from CWIX 2018 testing.

In 2019 the NATO M&S COE and USA GMU C4I and Cyber Center presented a briefing on the SISO C2SIM development process, including information on the final draft prepared for balloting, and also on the validation process conducted by MSG-145 in CWIX 2019 and the MiniEx. This also included a brief on development of the Autonomous Systems extension.

4.4 I/ITSEC DEMONSTRATIONS

As part of its objective to educate the community of practice, MSG-145 has provided a regular status briefing and demonstration at I/ITSEC held in Orlando at the end of November. This presentation is offered multiple times during each I/ITSEC meeting in the NATO booth and focuses on the capabilities of C2SIM and recent work by MSG-145 and SISO C2SIM PDG. Normally it has been accompanied by a demonstration describing recent development or testing, for example the CWIX testing done that year.

4.4.1 I/ITSEC 2016

During I/ITSEC 2016 the group's co-chairs gave a C2SIM Tutorial, this included presentations covering the topics of C2SIM Interoperability benefits, the C2SIM standard including the SISO process, examples of the C2SIM use cases in simple environments and the aims and plan for the MSG-145 group. The session was well attended by representatives from a number of different nations, with both civilian and military personnel.

The C2SIM Sandbox was in its first year in 2016 and was the subject of a proof-of-principle demonstration. The initial VPN-based remote desktop capability of the Sandbox was demonstrated, providing for remote operation of the C2SIM Reference Implementation Server with a simple task assignment in the VR-Forces simulation and results displayed on the C2SIMGUI editor. Because the new C2SIM standard was still in initial development, the demonstration was based on legacy C-BML implementations.

4.4.2 I/ITSEC 2017

In 2017 the C2SIM Sandbox demonstration at I/ITSEC was based on the systems tested at CWIX 2017. These were an early draft of C2SIM implemented by GMU C4I and Cyber Center as an interface for VR-Forces, combined with a legacy IBML09 implementation to JSAF provided by the UK Dstl, operating through the backward-compatibility capability of the C2SIM Reference Server, with orders entered and results displayed on the C2SIMGUI editor.

In addition, a demonstration of an implementation of a C2SIM Air Operation Extension (AOX) was performed as a prototype to prove the concept feasibility of interfacing legacy simulation, DirectCGF, and C2, Starlinx, which is native L16. For this purpose a C2SIM/L16 was developed highlighting the benefits for a non-Tactical Data Link Simulation to provide an air situation under the control of a C2 system. The C2SIM AOX draft was the first step to develop a more effective AOX.

4.4.3 I/ITSEC 2018

A demonstration was given at I/ITSEC 2018 using the early SISO C2SIM PDG drafts. The demonstration was a condensed variation of the setup used at the CWIX in 2018. In the scenario, two UAVs were tasked to patrol some areas, and a maneuver platoon was tasked to seize an area. The UAVs were simulated in JSAF (controlled by Dstl UK), the platoon was simulated in the system KORA (controlled by iABG), and VR-Forces mainly simulated the Red forces (controlled by George Mason University). KORA and VR-Forces used an early version of the C2SIM standard, while JSAF used the legacy format IBML09 operating through the backward-compatibility capability of the C2SIM Reference Implementation Server. Blue orders were issued in C2SIM format by the Norwegian joint C2IS NORCCIS with the web-based remote extension SWAP provided by FFI. Red orders were issued from the C2SIM editor in the C2SIM Sandbox. Figure 4-2 shows some of the activities.

4.4.4 I/ITSEC 2019

Two sets of demonstrations were given at I/ITSEC 2019. One was based on the French-German development of Air Operations using TDL and the other on the USA-Germany-Italy-UK MiniEx Bogaland scenario. Both these demonstrations were part of a wider-ranging presentation covering the groups' recent work and future plans. Figure 4-3 shows some of the activities.

The demonstration based on the MiniEx included KORA from Germany, JSAF (partially with legacy IBML09 interface), and VR-Forces from the MSCOE-Rome. The initial port of the C2SIM Sandbox to MSCOE-Rome was used, including the C2SIM Reference Implementation Server and the C2SIMGUI editor. The KORA ground forces, JSAF UAVs, and VR-Forces UGV were demonstrated carrying out their initial MiniEx orders and the remote operators interacted with the NATO booth at I/ITSEC by Internet conference as had been done in the MiniEx.

Figure 4-2: MSG-145 Activities at I/ITSEC 2018.

Figure 4-3: MSG-145 Activities at I/ITSEC 2019.

4.4.4.1 Air Operations

France and Germany presented their evaluation of the C2SIM based on the Air Operation use case. The presentation included a live demonstration illustrating a Destroy of Enemy Air Defences (DEAD) scenario. The scenario runs a Blue force composed of New Generation Fighters (NGF) carrying lightweight drones, enhanced legacy fighters and Unmanned Air Vehicles (UAVs), all monitored and controlled by an Airborne Early Warning and Control System (AWACS) through a tactical data link network. The Blue forces faces a Red force composed of Ground Based Air Defence (GBAD) systems and a quick response force to intercept intruders.

The scenario is simple but representative of a real air operation: the Blue jets fighter ingress from west to east into a hostile territory, Blue UAVs maneuver to wake up the Integrated Air Defence System (IADS) and to jam the medium and long range GBAD systems, Sol-Air à Moyenne/Longue Portée (SAMP and SALP). Once the Blue force is detected, GBAD missiles are launched; in response NGFs launch drones both to protect the NGFs to serve as primary target for the missiles and to destroy the threats. The progression goes on and the Blue force faces and destroys the enemy quick response force, the Blue force finally destroys the high value target and return to base, the Blue force wins, the missions is successfully fulfilled. Figure 4-4, shows the DirectCGF screen capture illustrating one vignette of the scenario “when the Quick Reaction Alert (QRA) targets the NGFs but is destroyed in combat”.

Figure 4-4: DirectCGF View of Air Operations Scenario.

The architecture supporting this demonstration involved an Air C2 surrogate (C2LG from FKIE) and an air simulation (DirectCGF from DIGINEXT). C2LG played the AWACS, C2LG was installed in Germany and was operated remotely at the NATO booth through a lightweight client (web browser). DirectCGF played the Blue and Red forces, it was deployed and operated at the NATO booth. To enable the message exchange between the systems, AIRBUS provided a C2SIM communication server, this server is part of the ELLIPSE interoperability solution.

This use case is interesting in many ways. It addresses Air Operations while historically C-BML was mostly a technology used for Land operations. TDL messages in Air Operations do differ drastically from the way orders and reports are exchanged in Land operations regarding the temporality / frequency of the messages and the absence of "superior/subordinate" relation between the sender and the receiver. Position reports are sent periodically (every 12 seconds on the PPLI subnet from non-C2 units (the jet fighters) to C2 unit (the AWACS) but way faster on a Fighter-to-fighter subnet if used); non-C2 units publish their positions directly to the network without knowing the C2 unit: the network becomes itself the recipient of the messages and one actor of the scenario (the C2 platform can be relieved by another one without warning the non-C2 units). The tactical situation sent from the C2 unit, which is a set of tracks and the result of combined detections, is broadcasted to all non-C2 units without specific recipients.

The messages demonstrated during this presentation were:

- Initialization message (for the initialization of the systems);
- Orders (C2SIM TDL messages):
  - Investigate;
  - Attack;
  - Engage; and
  - Return to base.
- Reports (C2SIM TDL messages):
  - PPLI;
  - Detections, and
  - Drop.

The exchanges of the C2SIM messages during the demonstration are illustrated below. In both illustrations, the deployment is the same; the names of the applications appear in the screens of the laptops. The first illustration, Figure 4-5, shows the message flow for initialization: the C2SIM initialization file is loaded in C2LG and then is sent to DirectCGF for its initialization. The second illustration, Figure 4-6, shows the messages flow during execution: the C2SIM orders sent from C2LG to DirectCGF and the C2SIM reports sent back from DirectCGF to C2LG.

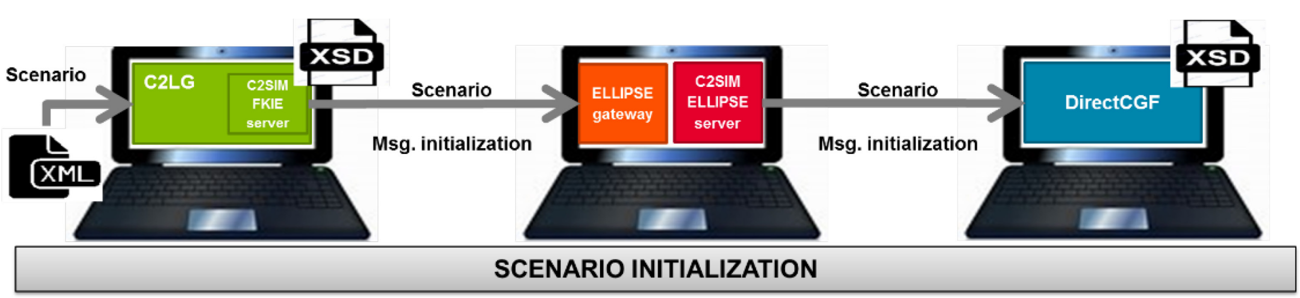

Figure 4-5: Flow of Messages for Initialization.

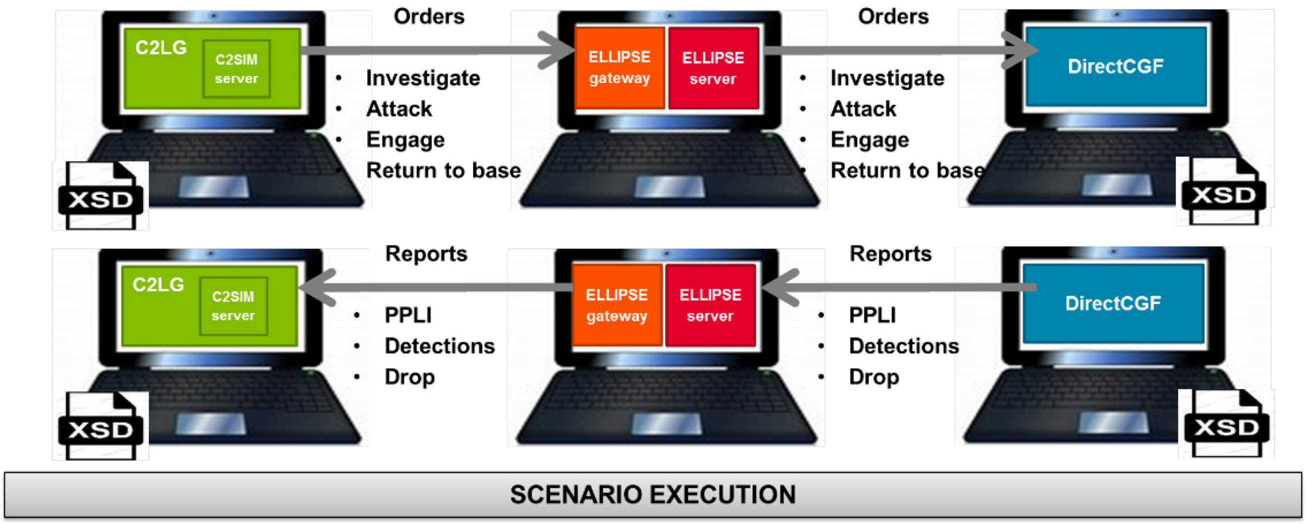

Figure 4-6: Flow of Messages for Execution.

4.4.4.2 MiniEx

Vignettes from the MSG-145 USA-German-UK MiniEx Bogaland scenario of May 2019, described above in Section 4.2, were re-run as public demonstrations. This demonstration was based on the GMU C2SIM Sandbox and included participants connecting applications located in the USA, Germany, Italy and UK.

4.5 ICCRTS

MSG-145 authors have presented papers each year in the annual International Command and Control Research and Technology Symposium, with the intention of keeping the C2 research community informed about C2SIM. The papers are identified in the References/Bibliography (see Chapter 8).

4.6 SISO SIW

MSG-145 has provided technical presentations every year at the SISO Simulation Innovation Workshop (SIW) in Orlando, with the intention of keeping the military simulation standards community informed about C2SIM. These address various aspects of the C2SIM standard development, the supporting technologies developed for it, and the role of MSG-145 in supporting and validating the standard. The papers published by SISO for these presentations are identified in the References/Bibliography (see Chapter 8).

4.7 NATO MODELLING AND SIMULATION GROUP ANNUAL SYMPOSIUM

MSG-145 authors have presented papers nearly every year in the annual NMSG Symposium, with the intention of keeping the NATO modelling and simulation community informed about C2SIM. The papers are identified in the References/Bibliography (see Chapter 8).

4.8 NATO ACT TIDE SPRINT

Members of the group have attended NATO ACT TIDE Sprint events from 2016 onwards, participating in the M&S tracks and liaising with the ACT coordinators. C2SIM is seen as a particularly useful capability to incorporate in Federated Mission Networking (FMN) which is being supervised by ACT. Conversely, TIDE SPRINT events have provided input into MSG-145, for example, in the way scenario development is conducted through an architecture-focused mission thread approach. TIDE SPRINT events support ACT by:

- Helping to deliver bottom-up improvements to interoperability amongst Alliance and Partner Nation C2 capabilities;
- Supporting the transition from stove-piped capabilities to highly networked and cross functional C2 systems (e.g., with FMN);
- Encouraging innovation through knowledge sharing and collaboration, including national expertise, industry and academia; and
- Providing underpinning technical and conceptual support to key NATO concepts and defence planners.

C2SIM fits well with the aims of ACT and FMN.

4.9 MULTILATERAL INTEROPERABILITY PROGRAMME (MIP) MEETING

MSG-145 briefed the February 2020 MIP Meeting on the C2SIM standard and the validation work conducted in 2019 by MSG-145. The MIP is interested in the possibility that simulations, linked to MIP-4-based C2 systems by the use of C2SIM, might provide a useful test environment for the system of C2 systems. It is not clear whether the MIP will pursue this. However, the exchange of information proved valuable. In particular MSG-145 learned that the FMN (described in Section 4.8 above) will have MIP-4 as its Spiral 4 C2 standard. Development of a MIP-4 to C2SIM gateway should therefore be a priority for the NMSG, to facilitate C2SIM in FMN.

4.10 DSET

The Defence Simulation, Education and Training (DSET) conference was first held in the UK in 2016 to facilitate international military to military engagement and to inform industry of the challenges and opportunities ahead from a customer perspective. The agenda continues to be set by a military panel and speakers are invited and typically from the military or government. The conference has grown in numbers from 100 to over 400 and in 2019 and 2020 a pre-conference workshop on NATO M&S activities and the role of standards work in SISO has been held. On both occasions C2SIM has been presented to illustrate the development of the standard and the interaction by NATO and SISO.

4.11 SIMTECT 2017 AND 2019

SIMTecT is held every two years under the organization of Simulation Australia. In 2017 a one-day Masterclass on C2 – Simulation was held based on the C2Sim Lecture Series (NMSG 141) which provided insights from NMSG 048 and 085. In 2019 two presentations on C2Sim were given. One by Thales-UK and Dstl and the second by Thales Australia based on their experiences in connecting a Maritime C2 system to a simulation.

4.12 PROMOTIONAL VIDEO

In its final year, MSG-145 assembled a video presentation that can be used to explain its work and promote NATO adoption of C2SIM. The video files were produced by local teams from Germany, CWIX 2019, MSCOE, Norway, Sweden, and the UK. The video was produced by the commercial vendor IntrepidTV under funding from the NATO M&S Coordination Office, using a script developed by the GMU C4I and Cyber Center. The video is available on the NATO STO website [20].

Chapter 5 – LESSONS IDENTIFIED AND LESSONS LEARNED

The NATO Lessons Learned Handbook [21] distinguishes: *lessons identified, lessons learned,* and *lessons learned information* as follows:

Table 5-1: NATO Lessons Learned Handbook Definitions.

Lesson Identified (LI)	*This is a mature observation with a determined root cause of the observed issue and a recommended remedial action and action body, which has been developed and proposed to the appropriate authority.*
Lesson Learned (LL)	*An improved capability or increased performance confirmed by validation when necessary resulting from the implementation of one or more remedial actions for a lesson identified.*
Lesson Learned Information (LLI)	*Any information that is generated as part of a LL process as well as information generated after activities that is not formally part of a LL process such as after-action reviews, periodic mission reports, first impression reports, final exercise reports, trip reports, hot wash up output, meeting minutes, etc. (proposed definition).*

This chapter describes the LI and the LL from the various experimentation events, communication events and other activities such as analysis or modelling. Some of the LIs are not particular to C2SIM but are included as they are important to consider when using C2SIM in systems.

5.1 LESSONS IDENTIFIED

Table 5-2: Lessons Identified.

Lesson Identified	Comment
National C2IS with C2SIM implementations are needed. This could be facilitated by a MIP-4 to C2SIM gateway.	GMU C4I and Cyber Center is working to get a C2SIM-enabled international version of the widely used SitaWare commercial C2 system.
C2SIM adoption will depend on inclusion of the C2SIM Standard in the NATO FMN.	NMSG is working to facilitate this.
C2SIM as a Service forms a natural part of MSaaS.	MSCOE is working on a prototype to encourage this.
Use of the GSD to assist in the development of C2SIM capabilities.	The GSD best practices in developing operational and conceptual scenario prior executable scenario (e.g., C2SIM schemata) was applied to define the Air Operation Extension (AOX). The approach is effective and easy to master for the information exchange requirements from military capability down to technical implementation.
The availability and cost of cloud services can both be limiting factors for their adoption.	This may get better as the industry matures.

Lesson Identified	Comment
Cloud environments need to be easy to procure, configure and use.	Not currently true; may happen as they mature.
In a cloud environment there are potential bottlenecks and security issues when sharing messages.	This needs more study and experience.
The GMU C2SIM Sandbox Reference Implementation, open-source tools and libraries were VERY helpful.	After familiarization, most users were able to implement their own instantiations very quickly.
The schema for ObservationReport has an xs:choice for ObservationType.	There should be an optional xs:sequence because you probably want to report name, location, subject type, activity and health all at once the very first time. Then only update ones that change (e.g., location). Detail reported to SISO C2SIM PDG.
Need key operating procedures and Information Exchange Requirements (IERs).	Express in terms of C2SIM ontologies and use with SISO GSD.
Good Human-Machine Interfaces (HMI) are needed.	This is a property of applications; need those with good HMI to adopt C2SIM.
Virtual and Constructive simulations need to better represent operational behaviors.	Human, equipment, doctrinal, organization, population, etc.
Need to be able to extract data for analysis.	Server logs are available and data they contain is tagged. As with a simulation-only system there is scope for specialized logging and analysis tools to be developed.
Need to be able to coordinate tasks from different orders.	Using task UUID can enable this, the logic though needs to be managed by the participating C2SIM applications.
In order to use high performance graphics there is a requirement to connect to a Graphics Processing Unit (GPU).* This remains true in a Cloud Computing environment.	GPU technology enables every Virtual Machine (VM) to get GPU performance just like a physical desktop. Work that was previously done by the CPU is now offloaded to the GPU, providing users with a better experience.
GMU WS STOMP subscription topics.	The GMU WS supported a number of legacy protocols including: C-BML (at least two schemas), MSDL and IBML09. Better use of the STOMP subscription topics would have made these easier to use.
The range of possible tasks (DesiredEffectCode and TaskNameCode) is significantly greater than the possible tasks or behaviors available in many of the simulations, e.g., VBS3.	These codes have largely been derived from JC3IEDM which provides a large set of tasks so federation agreements and the mapping of C2SIM tasks to simulation capabilities need specifying carefully. There could be some hierarchical structure or inheritance so that if a behavior/task is not understood by a sim, it gets rolled back to a more generic task.

Lesson Identified	Comment
The standard specifies more than one coordinate system: GDC, GCC, UTM and MGRS.	Using only geodetic (lat, lon, altitude) for all C2SIM messages could simplify their exchange and interpretation. Any coordinate transformations should be to/from GDC in the client applications/middleware.
The communication network in the Object definitions appears to provide powerful capabilities especially for representing Cyber/EW effects.	Experimentation to exploit this capability should be conducted.
For CWIX and the MiniEx IssuedTime for orders was largely ignored. Issued time was set to the time the order was pushed to the server. If an order was set with a future timestamp, e.g., 1 hour, would the server hold it for 1 hour then send it, or would the server send it as normal and the sim should hold it for 1 hour?	Time management for C2SIM is an area where an understanding how C2SIM systems should implement time-stamping, including developing recommended best practice, dynamic modification of time stamps for a number of use cases: message replay, AAR, FTRT simulation. The C2SIM Core ontology provides for appropriate values of time, but implementation of C2SIM coalitions will have to mature to make effective use of this.
For some simulations, e.g., OneSAF C2SIM-Initialize does not provide enough information to do a complete initialization.	The C2SIM XML schema does not allow new fields to be added very easily. A schema augmentation capability has been defined using external schema files but is difficult to use. Users need to learn to extend the ontologies (much easier) which will result in extended XML schema. Also, the SISO C2SIM Product Support Group (PSG) could extend the schema to provide for new data classes that are broadly useful.
Global initialization files require very large amounts of data to be sent across the network.	Building the scenario file on each system is possible. Sending a partial initialization message would require a much smaller information exchange. However, the C2SIM initialization design is intended to allow plug-and-play coalitions; instant interoperation is not possible where files must be coordinated in advance.
C2 is not just about C2 systems.	It is a complex, knowledge intensive, socio-technical endeavor. C2SIM is principally an enabler for the technical support systems.
Legacy systems are often difficult to work with.	This has been shown many times, but they are important because of their persistence and prevalence.
Many C2SIM-enabled systems currently do not get far enough along the “Adoption, Utilisation and Utility waterfall” [22] to become widely adopted.	This situation will improve when better embedded and easier to use capabilities are specified and acquired.

5.2 LESSONS LEARNED

Table 5-3: Lessons Learned.

Lesson Learned	Comment
Simulation developers have taken to C2SIM, e.g., MäK and MASA but it has only had limited adoption by C2 system developers.	Two cases of the latter are STS and Systematic who both provided limited support for NMSG C2SIM experimentation purposes.
C2SIM Initialize for late join.	Where a server operates on a publish/subscribe basis there is a need to cater for late joiners/rejoiners. A late join protocol was provided by the GMU WS and implemented in a number of participating systems.
C2SIM Extension process worked well but requires a learning process.	Air Operation Extension (AOX) was developed in using the C2SIM process. Annex C provides detailed information regarding the process execution.

Chapter 6 – FUTURE EXPLOITATION

6.1 SCOPE OF EXPLOITATION

The scope of exploitation of the C2SIM interoperability standardization and underpinning technology development is wide and can provide cost and time benefits in the following areas:

- Collective Training – in particularly C2 training of joint or component HQ through Computer Assisted or Command Post Exercises (CAX or CPX);
- Mission Planning and Rehearsal – to assess mission plans or COAs and rehearse before deployment;
- Operational Decision Support – to provide likely outcomes to decision making during the conduct of operations;
- Autonomous Systems – to provide commanding or controlling systems designed with greater autonomy; and
- Design and Acquisition – to support requirements, testing and developing of C2 systems for future complex multi-domain operations.

MSG-145 has identified the former following potential exploitation areas for C2SIM. These are driven by the national use cases.

This section outlines a number of ways in which C2SIM-enabled systems may be exploited in a number of domains. The section is not exhaustive but is provided to give an indication of some of the potential benefits identified by activity group members.

6.2 FEDERATED MISSION NETWORKING

Federated Mission Networking (FMN) is a major NATO thrust in support of interoperability, with a "Day Zero" focus calling for NATO nations and partners to achieve interoperability before it is needed again as it as in the Afghan Mission Network. Modeling and simulation should provide a very significant part of this capability, for collective training, course of action analysis, mission rehearsal, and evaluation of proposed/planned systems. The envisioned capability should include state-of-the-art information technologies. Participation in the FMN specification process by the NATO Modelling and Simulation Group (NMSG) is important to achieve this. In March 2020 the FMN specification process will begin Spiral 5 which includes M&S. Continued activity to specify M&S is planned to extend through Spiral 6, extending a total of four years. Aspects where NMSG is particularly well equipped to help specify the FMN include C2SIM.

6.3 TRANSITION SANDBOX TO M&S COE

The C2SIM Sandbox has been available from the George Mason University C4I and Cyber Center via Internet through Virtual Private Network (VPN) since 2017. From 2020 it will be deployed at M&S COE and at least part of it will be available in the OCEAN platform implementing the "C2SIM as a Service" concept. Migration of the C2SIM Sandbox to M&S COE is part of the completion of C2SIM technical activity handover to NATO, to allow C2SIM testing and experimental use to continue towards a more widespread operational C2SIM adoption. So, the following forms of testing continue to be available in the future:

- 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; and
- Distributed configurations of all sorts.

6.4 C2SIM IN LEGACY C2 SYSTEMS

Norway has participated in several MSG demonstrations, using both the former C2 system NORTaC-C2IS and the current NORCCIS. Lacking native support for C2SIM, gateways were built that extracted ORBAT and order information from the C2 system databases and converted the information to BML and MSDL formats. C2LG was used to add missing information needed for simulations (for instance a synchronization matrix). MSG-145 still uses C2LG and equivalent tools, since current C2 systems mostly do not implement C2SIM. Reports sent to the C2 systems were translated to standardized military formats (like OTH Gold, APP-11 messages or NFFI).

An important issue related to using legacy C2 systems is the use of time. C2 systems usually use wall clock time and verify the validity of incoming messages. This implies that reports coming back from simulation systems running faster that real-time with a "future" time stamp may be rejected, unless the C2 system is prepared to accept it. Simulation systems may run the same COA or variations multiple times, starting from the same time, unlike C2 systems. C2 systems must be able to handle a new set of reports from another run covering the same period as earlier. Due to the capability of running faster than real-time, and maybe repeating a time sequence multiple times, the number of reports generated from the simulation systems may exceed what is expected by the C2 system.

Thus, in order to fully exploit the potential of C2SIM, future C2 systems need to implement both the capability to issue digital orders and to handle logical time or simulation time.

6.5 C2SIM CONNECTING TO CURRENT C2 SYSTEMS

GMU C4I and Cyber Center, in executing their contract to the US Army Modeling and Simulation Office, created a C2SIM interface module for the commercial C2 system SitaWare that was adopted recently by the US Army. The module used the Web service interface of SitaWare to display situational awareness from C2SIM report messages. Implementation was straightforward and required less than two staff-months of effort. Contract restrictions precluded sharing this software with other MSG-145 national teams, so in CWIX 2019 and MSG-145 MiniEx C2SIM validation SitaWare was used only at USA sites Army Test and Evaluation Command (ATEC) and Naval Postgraduate School (NPS) where it provided a more effective situational awareness display than the C2SIM editor used at other sites. A commercial version of SitaWare with C2SIM interface would provide significant support to C2SIM adoption in NATO.

6.6 C2SIM TO SUPPORT ACQUISITION

The systems of Defence are increasingly more complex, because integrating more components, heterogeneous and disparate lifespans. The reduction of the risks in the various phases of an armament program (upstream of feasibility until the startup, even with the withdrawal) then becomes an essential stake for control of the operational need, technical requirements achievements and global functional chains consistency through the life of the program. Within sight of the capability approach, it is required to improve the methods and tools of modeling and simulation to the service of the architects, for the assistance with the analysis, the design, the realization, with the evaluation even with the management of configurations and the drive of future systems of systems.

With no doubts, it is currently proven that M&S benefits are multiple during the systems lifecycle, such as:

1) Requirements:
    a) Global architecture concept evaluation;
    b) Tradeoff analysis between operational capabilities and performances; and
    c) Choice of most effective architecture against various criteria.
2) Specifications:
    a) Technical feasibility demonstration;
    b) Identification of the most adequate organization for the development; and
    c) Measurable specifications wording.
3) Realization:
    a) Exploration of different options for manufacturing the system in order to optimize the design of the solution; and
    b) Technical constraints fulfilment.
4) Evolutions and integration within the systems of systems:
    a) Consistency check of different versions of the same system to comply with operational contract or different versions of systems gathered together to provide systems of systems; and
    b) Reuse of existing components and sub-systems to build new systems.

C2SIM is really an enabler to match with the previous use cases. It eases to mirror flow of information between systems, sub-systems, components whatever the levels of detail required from exchange requirements down to technical data. Hence, it contributes when using M&S to master the interoperability and therefore interface exchanges from top-level architecture down to solution design and realization by replacing models at more or less accuracy with real components when they are ready to integrate. This increases the systems of systems confidence, prior the delivery, in testing the requirements fulfilment during the integration stage by running the overall architecture against scenarios developed earlier at the beginning of the acquisition process. In such manner, C2SIM contributes to fill the gap between each milestone of systems lifecycle.

6.7 C2SIM IN SUPPORT OF NATO C2 VISION

Within the NATO Allied Command Transformation (ACT) C2 vision for 2030 (Figure 6-1 [23], [24]), NATO recognizes decision making as one of the key process categories: Collecting [of data, information, intelligence], Decision Making (i.e., MDMP) and Effecting, (i.e., undertaking and then assessing some agreed action). It also envisions a fully distributed cloud environment to support the concept. The cloud environment will, among other things, host decision support tools including M&S capabilities and provide global reach-back. This is often called a Single Information Environment (SIE).

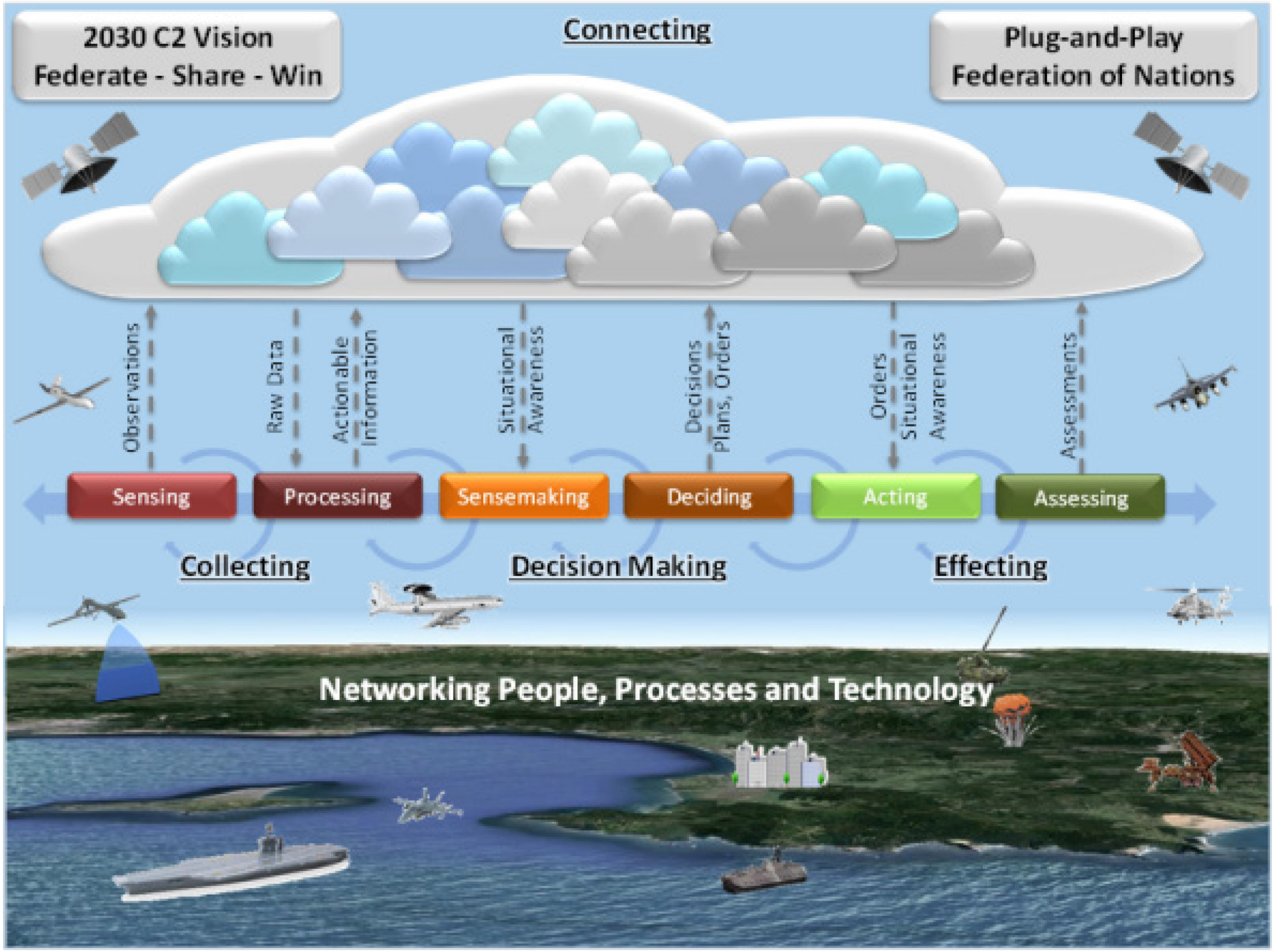

Figure 6-1: ACT C2 Capstone Concept[1].

Of the three main areas outlined there is particular scope for C2SIM to be used to help decision making through the use of decision support tools, including simulations accessed remotely. C2SIM-enabled applications would provide the information exchange between the operational decision makers and a cloud-hosted (MSaaS) simulation capability. The decision support tools could cover a number of functional areas including:

- Constructive simulations capable of running in a Faster-Than-Real-Time (FTRT) mode;
- Route planning tools;
- Logistic simulations;
- Resourcing and deployment; and
- Communications simulations.

In this vision all things may be connected: people, places, platforms, organizations, applications, networks, data and processes. Ideally this will also include connecting to and possibly sharing data and information with

[1] Acknowledgement to NATO ACT.

external parties, including: International, Government and Non-Government Organizations (IO, NGO and GO). Good, resilient and secure connectivity and interoperability is fundamental to the concept.

Currently SA is presented as a COP, usually as icons displayed on a map. There is scope for much richer information than can be inferred simply from location data. An icon could represent the gateway to access related geo-information, intelligence on and from a unit or area and any associated decision support tools or capabilities.

FMN initially focused on C2 interoperability based on lessons identified through NATO's deployment in Afghanistan. The role of M&S is recognized as a tool to provide in-theatre and potential reach-back connectivity to support both training and operations. This concept has been elaborated in more detail in [25].

Chapter 7 – CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The MSG-145 TA's program of work covered the following main areas:

- Exploit C2SIM with use cases through an operational, conceptual and executable scenario development process by engaging the operational community;
- Develop required extensions to the C2SIM Logical Data Model Core for specific functional areas;
- Inform the standards development process and motivate suppliers to develop products;
- Educate the community of practice on C2SIM technology employment and encourage nations to use the standards; and
- Make recommendations for "covering" the C2SIM standard with a STANAG.

7.1.1 How the Group Met the Objectives

The work was organized to cover these areas and this has been described in earlier sections. A number of representative use cases were developed in consultation with the operational community to exercise the C2SIM standard. Where necessary, new extensions were made for the C2SIM LDM, for example the ASX, and these experiences helped inform the M&S community in general and the SISO C2SIM PDG in particular. These activities were backed by practical experimentation and exercises, e.g., through participation in CWIX events. Feedback supplied to the PDG enabled the latter to address any technical problems uncovered during the work.

A number of outreach activities were undertaken: tutorials, conference papers, demonstrations to inform the wider community: military, government, industry and academia of the benefits of the work.

7.1.2 Exploitation

MSG-145 members are working to obtain implementation of C2SIM in C2IS, C2SIM as a Service, and C2SIM in NATO FMN.

7.1.3 Extensions to the Standard

Two example C2SIM extensions were developed: ASX for autonomous systems and AOX for TDL exchange. Developing these extensions demonstrated that the processes and tools envisaged by the SISO C2SIM PDG provide a practical method to extend the standard. ASX is in development as a potential extension to the balloted standard and AOX is expected to be proposed at a future date.

7.1.4 Inform the Standards Development Process

Both the development and testing of C2SIM, including the ASX and AOX domain extensions, and observations from the practical experimental work (CWIX and the MiniEx) have fed into the SISO C2SIM PDG and helped that group's developers produce a practical standard.

7.1.5 Educate the Community of Practice

Group members presented papers at relevant international events including: NMSG business meetings; CA^2X^2 Forums; ITEC, I/ITSEC; ICCRTS; ACT TIDE SPRINT and SISO SIW, gave demonstrations and participated in a number of national and international events. As a result of the group's work a number of companies have developed C2SIM capabilities in their products for both commercial and evaluation purposes. A Research Technical Course has been proposed in order to accelerate this process.

7.1.6 STANAG Process Transition to NMSG Standards Sub-Group

The MSG-145 TA has made significant progress in advancing the standardization of C2SIM interoperation toward the goal of providing a capability that can improve the decision-making and training in coalition military operations. Starting with a concept, the community involved in C2SIM, both in NATO and SISO, has achieved continued progress toward the goal that, in the not too distant future, military coalitions will be able to come together and benefit from interoperating C2 and simulation systems across all nations participating.

Commendable progress has been made toward the goal of establishing a set of standardized, technically mature C2SIM interoperability products. The feasibility of C2SIM was previously demonstrated by MSG-048 and the utility of C2SIM interoperability has been demonstrated by MSG-085. MSG-145 engaged with the operational military community in the various NATO nations to provide evidence that the products that enable C2SIM interoperability should be an integral part of NATO and national C2 systems.

Annex D gives the STANAG Proposal prepared for the NMSG Standards Sub-Group (MS3).

7.2 RECOMMENDATIONS

Based on the results and findings of the MSG-145 a new TA is required to achieve the recommendations set out below.

7.2.1 Recommendation 1

A C2SIM STANAG should be proposed based on SISO C2SIM standard.

7.2.2 Recommendation 2

NMSG should promote the C2SIM standard to the nations and industry.

7.2.3 Recommendation 3

NMSG should promote the C2SIM standard to FMN and add the standard to the NATO Interoperability Standards and Profiles (NISP) and the NATO M&S Standards Profile (STANREC 4815).

7.2.4 Recommendation 4

Development of Decision Support and implementation tools need to be pursued to further develop an operational capability.

7.2.5 Recommendation 5

The level of experimentation should be extended to include more use cases to support operational plans.

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Annex A – C2SIM REFERENCE ARCHITECTURE

A.1 OBJECTIVE[1]

A lesson identified in the NATO activity MSG-085 [1] was that a "Reference Architecture" for C2SIM interfaces should be developed to facilitate C2SIM environment design. This annex provides the results of a study that has been performed in the framework of MSG-145 to start the development of this reference architecture. It should however be stressed that the work needed more input from the study group and didn't result in a completed RA and thus can only be used as an initial result.

The objective of this study is to introduce the concept of a *C2SIM Integration Platform Reference Architecture* (the meaning of which is explained in the following subsection) by taking the initial steps towards such a reference architecture. Because we don't want to put requirements on Simulation Systems or C2 Information Systems we only take the Integration Platform as the scope and not the complete C2SIM environment.

The aim of the *C2SIM Integration Platform Reference Architecture* (C2SIM IP RA) is to provide a "template" or "blue-print" for the development of C2SIM Integration Platform *solutions*. More specifically, the C2SIM IP RA:

- Provides terminology and architectural concepts that can be used in the description of a C2SIM IP solution architecture, and
- Provides guidelines, options, and constraints for making design decisions with regards to a C2SIM IP solution implementation.

The C2SIM IP RA leverages the concepts, definitions and several of the architecture building blocks of the NATO MSG-136 "MSaaS Technical Reference Architecture" [2].

The C2SIM IP RA should answer the following questions:

- What are the architecture building blocks that I need to consider in designing a C2SIM IP solution?
- What are the requirements and standards that technology should meet that I use for the realization of an architecture building block for a C2SIM IP solution?
- What are some of the key architectural decisions I need to make when designing a C2SIM IP solution, or assessing a C2SIM IP solution architecture?

A.2 BACKGROUND

At the end of the 90s, digitizing military Command and Control (C2) using C2 Support Information Systems (C2IS) gained more and more interest and C2 communication, not only between humans but also between humans and C2IS and among C2IS, became more common. Since the 2000s the interest grew in using simulations to stimulate and be stimulated by C2IS and communication between C2IS and Simulations has become less interpersonal and more data-oriented.

Since Simulation Systems and C2IS come from different domains, the 'languages' to describe the interactions in both domains differ [3], [4]. The C2 community uses a variety of standards such as formatted messages, data links (e.g., Link 16), information exchange data models such as the Joint Consultation, Command and Control

[1] References given in this annex are tabulated separately.

Information Exchange Data Model (JC3IEDM) and different kinds of transport mechanisms. The simulation community uses standards for building simulation federations. Within NATO the High Level Architecture (HLA) standard (STANAG 4603) is used. Therefore Interoperability between Simulation Systems and C2IS involves bridging these two separate worlds.

The Distributed Simulation Engineering and Execution Process (DSEEP) [5] deals with the development and execution of distributed simulation environments. A simulation environment is a generic term, defined in DSEEP as: "a named set of member applications along with a common information exchange data model and set of agreements that are used as a whole to achieve some specific objective". The common information exchange model is called the Simulation Data Exchange Model (SDEM), specifying the data that may be exchanged at run-time. Member applications are defined as: "applications that are serving some defined role within a simulation environment". In HLA, one of the standards that are available for distributed simulations, a simulation environment as defined in DSEEP is called a federation, which is a federated system consisting of federates (member applications) which are loosely coupled systems that are connected through an enterprise service bus for data exchange. Since simulation environments that contain C2IS as member applications (which are actually live Simulation Systems) can be connected through different means than only enterprise services buses. Therefore, in order to avoid confusion, we will use the term *C2SIM environment* instead of C2SIM federation to designate environments consisting of Simulation Systems and C2IS, connected using a common C2-Simulation data exchange model. Work on a DSEEP overlay has been initiated [4] which discusses the issues when assembling C2SIM environments.

The notions that we use to describe C2SIM environments are:

1) Simulation environment consisting of Simulation Systems (e.g., an HLA federation);
2) C2 environment with interconnected C2 Information Systems (C2IS); and
3) C2SIM Integration Platform.

The *C2SIM Integration Platform* element represents the interface system via which the C2-Simulation data is exchanged. Although other architectures may be chosen, Figure A-1 shows a possible architecture illustrating these notions.

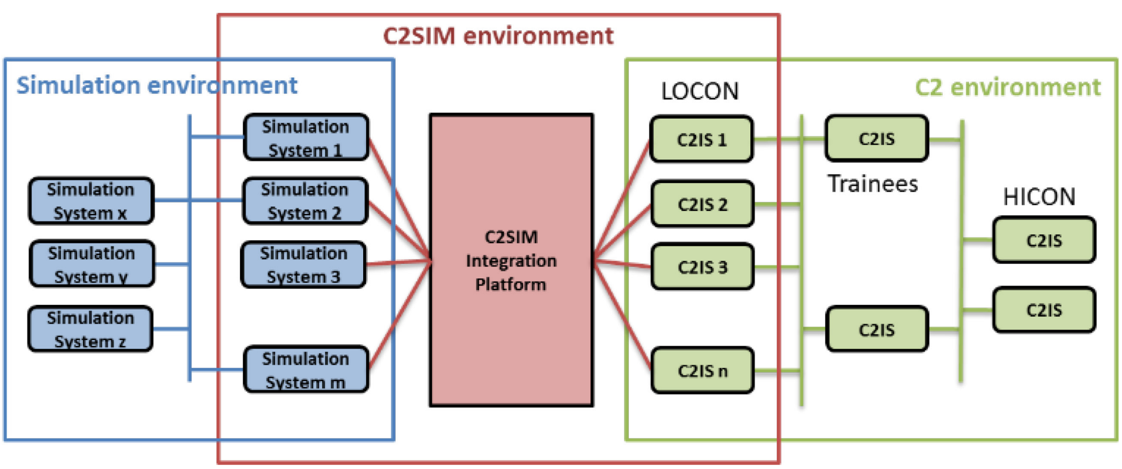

Figure A-1: Illustration of a Possible C2SIM Environment in an Example Architecture in Combination with a Simulation Environment and a C2 Environment.

Important to emphasize is that the C2SIM Integration Platform is not a replacement of the simulation environment run-time infrastructure (i.e., HLA-RTI). Simulation Systems must use the simulation environment run-time infrastructure to exchange data among themselves. Similarly, the C2IS remain to use their existing C2 communication infrastructure to exchange data in the C2 environment.

The only purpose of the C2SIM Integration Platform is to provide the capability to exchange data between C2 environment and Simulation environment. The information that is to be exchanged via the C2SIM Integration Platform is under standardization by SISO. The Data Exchange Mechanism however has not been standardized and several solutions can be found in literature.

A.3 LITERATURE REVIEW

C2-Simulation interfaces has been a research topic for several years and numerous papers have been published on C2-Simulation interoperability, integration, and standardization. Various technical solutions for different elements of C2-Simulation interfaces have been presented in papers. This section presents the results of a literature review with the aim to identify functionality in technical solutions for C2-Simulation interfaces. The functionality will be used for the definition of *Architecture Building Blocks* discussed later on in this document.

The following functionality has been found in literature:

- Data transformation;
- Protocol transformation;
- Data filtering;
- Data persistency;
- Simulation control;
- Interface monitoring and control; and
- Security.

These are discussed in the following sections.

A.3.1 Data Transformation, Protocol Transformation, and Filtering

Data and protocol transformation, and data filtering are common functions that have been found in several papers on C2SIM Interface solutions. These functions are typically used at system or sub-system (and architecture) boundaries, where data enters or leaves the (sub)system.

We define these functions as follows:

- Data transformation is the process of converting data in one format to data in another format. This includes – but is not limited to – data encoding, decoding, and conversion.
- Protocol transformation is changing the protocol by which data is transported, e.g., from HTTP to HTTPS in a network proxy.
- Data filtering is the process of removing certain data from the data stream. Several methods may be used to do this, such as topic or content-based filtering.

An example of data transformation functionality has been found in Ref. [6] where C-BML order/reports are translated between the C-BML Server from the George Mason University and the VR-Forces simulator from MäK. The data translation is done via a Bridging Application (see Figure A-2), which **transforms** C-BML data to a format suitable for VR-Forces. In a sense the Bridging Application does not only do data transformation, but also **protocol transformation** between the C-BML Server (RESTful) and the Remote Controller API in VR-Forces.

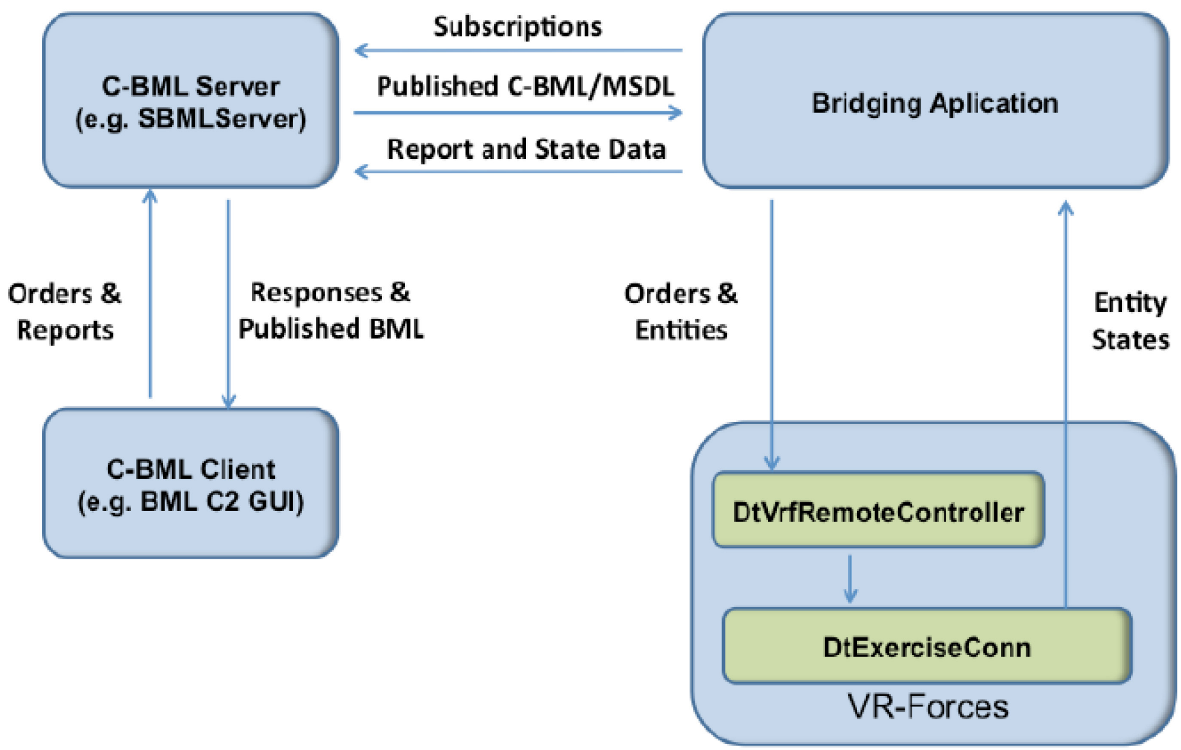

Figure A-2: MSDL/C-BML – VR-Forces Integration Architecture (from Ref. [6]).

In Ref. [7] another example of data and protocol transformation has been found. In this paper a Scripted BML (SBML) Server from George Mason University-based on the SAAB WISE platform is described (Figure A-3).

The SAAB WISE platform is a suite of tools from SAAB to achieve connectivity between different products, regardless of the protocols they use. This is basically achieved by using what have been called connectivity drivers and by graphically configuring data transformations between the different data models used in the drivers. A component of the SAAB WISE platform called *transformer* can be used in this configuring the transformations. It takes a set of input values, executes a predefined function using these values, and then generates a result as an output. Transformers are used in mapping values from one model to another.

In the solution described in the paper the transformers are used to **translate** among semantically equivalent schemata (BML/MSDL XML documents). The SBML Server can transform XML documents received on a REST interface to XML documents sent out on a Simple Text-Oriented Message Protocol (STOMP) interface. So, also protocol transformation takes place.

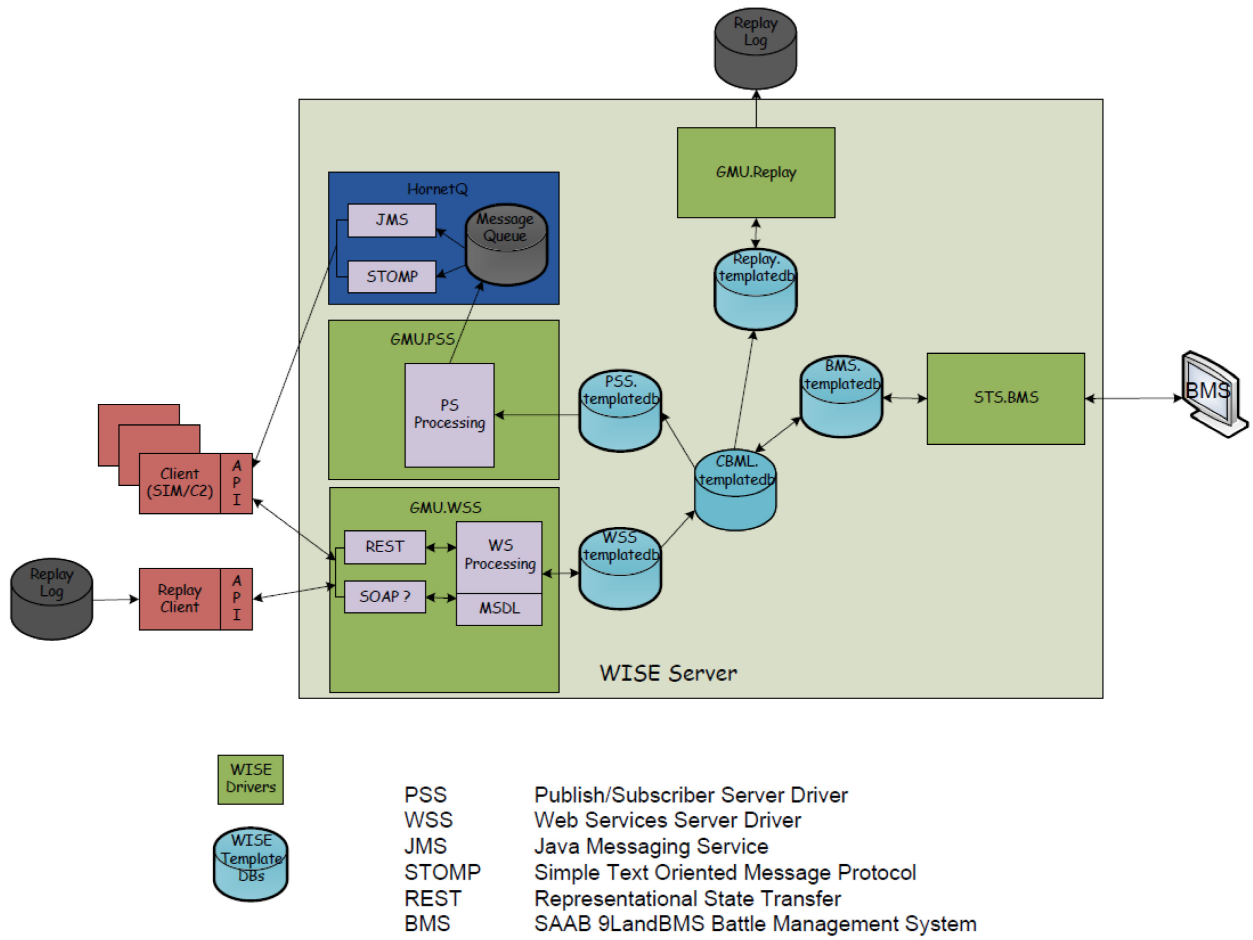

Figure A-3: The SBML Server, Based on the SAAB WISE Platform [7].

The mapping is described in an XML file. In addition, the SBML Server supports data **filtering** to restrict delivery-based on user-defined criteria. For this, the SBML Server supports dynamic definition of Publish/Subscribe Topics, i.e., topic-based filtering.

Another example of data **filtering** is frequency transformation, mentioned in Refs. [1] and [8] where it is concluded that in order to reduce the load on C2IS the frequency of the message stream from the simulations has to be reduced. However, we argue that this kind of data filtering should not be a function of the C2SIM Interface. It is the responsibility of the producing (C2 or Simulation) system or environment to provide data updates with the correct and agreed frequency.

In Ref. [9] a distributed C-BML Server is presented, achieved by interoperation between the SBML Server based on the SAAB WISE platform described in the previous paragraph and the FKIE BML server from Fraunhofer Institute for Communication, Information Processing and Ergonomics. The interoperation is achieved by connecting the STOMP and REST interfaces of both systems back to back, as shown in Figure A-4. Although the content of the data is not changed (only the external packaging), the B2B clients basically do **protocol transformation**.

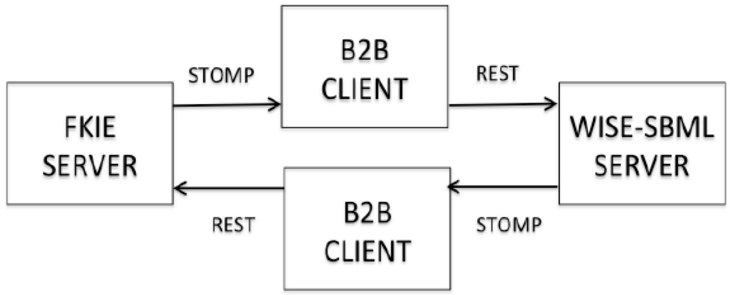

Figure A-4: C-BML Server Interoperation.

Further use of translation and transformation functionality is described in Ref. [10]. This paper describes a demonstration (VULCAIN) with C2IS, federations of simulations and gateways to exchange information between C2IS and the federations of simulations. The simulation environment consists of SWORD, VR-Forces and STAGE, connected through an HLA-RTI/NETN FOM. Gateways were developed to **translate/transform** SICAT messages to C-BML messages, and to transfer messages from a C-BML Server to the simulations.

In Ref. [1] requirements for message validation, correction and conversion have been stated. Validation of messages is required to check consistency with the doctrine, procedures and rules of engagement of both the sending C2IS and consuming simulation system. In some instances, a message may be deemed invalid. Therefore it may be rejected or it may be possible to correct the message based on knowledge of which business rules failed. Conversion of tasks can be required for different forces. For instance it is conceivable that, based on the explicit information contained in business rules that have been established for a specific national force (e.g., Norway) tasks can be converted to a task for another force (e.g., France) while taking full consideration of both the military capabilities of both forces and their difference in national warfighting doctrine.

Lastly, an example of a filter function in a C2-Simulation Interface was found in the Dutch national project called "Inforotonde" [11], where the Royal Netherlands Army C2IS (ELIAS) was connected with several other simulation systems via the SAAB WISE platform. A Network Simulation Service was used for the Royal Netherlands Army C2IS to **filter** (simulated) vehicle position updates before they enter the C2IS. The filtering was according to the available (simulated) radio networks to distribute data between (simulated) vehicles. Next to the filtering function, the server also performed data transformation and protocol transformation for the data coming from the C2IS transforming it from native C2IS format to C-BML. In this example the data filtering is a function of the simulation environment and not the C2SIM Integration Platform or C2 System.

A.3.2 Data Persistency

In all applications that were found in literature, the communication between the C2IS and Simulation has been asynchronous. Although synchronous communication is conceivable, asynchronous communication has been stated as a requirement in order to facilitate many functions that a C2SIM server could fulfil.

Asynchronous communication requires the use of data memory in the C2SIM services, e.g., in the form of a database. How the messages are put in the database differs for the different applications found in literature. In [12] four servers are described, the CBMS server from VMASC, the FKIE server from Fraunhofer, the Ellipse server from Airbus and the WISE-SBML Server from GMU/SAAA. The first three input and store whole XML documents without parsing them. This is fast but it is not capable of translating since the server does not pull out individual data values (a process called "parsing") so it can't reassemble them into a translated document. The fourth does parsing before storing and therefore enables translation services.

Data persistency is also discussed in Ref. [9], where BML data is stored in a relational database and is used to support a scripted SBML Server. The scripted server can convert between a relational database and XML documents based on a set of mapping files and XML Schema files.

A.3.3 Simulation Control

Simulation control concerns functionality to control a simulation, provide input to the simulation, and collect output from the simulation.

In general, different **modes of operation** can be distinguished for simulation control. Many of the C2-Simulation Interface solutions that are discussed in literature concern training, i.e., where the simulation is real time and represents the real world while another mode of operation is for decision support. One can imagine that requirements for functions such as start, stop, pause, resume and rewind differ depending on the mode of operations. In Refs. [3] and [4] the fact that simulation systems in general manipulate and manage time is discussed. This is a challenge when integrating with systems which are designed to use only wall-clock time, like C2IS. Some other examples of the decision support mode of operation can be found in Refs. [13] and [14]. These characteristics will probably pose requirements for start, stop, resume and rewind functionality in the C2SIM Integration Platform.

Ref. [15] discusses a distributed simulation capability to support experimental requirements of a range of communities including Command and Control (C2). One recommendation is to support **scenario check-pointing** to enable the restart of a scenario part-way through. The checkpointing itself is for the simulation environment, but the initiation and control over this falls under simulation control in the C2-Simulation Interface.

Ref. [10] has already been mentioned in Section A.3.1 and describes a demonstration (VULCAIN) with C2IS, federations of simulations and gateways to exchange information between C2IS and the federations of simulations. To **initialize** the simulation environment a "Battlebook" was used which captures the label, identification code, type and other features of objects modelled by the simulation environment. In the future the Battlebook content should be generated from MSDL as much as possible. Data from the simulation environment is subsequently used to initialize the C2IS. In VULCAIN the C2IS are initialized with (aggregate level) data from SWORD.

Multiple systems in a C2SIM environment may all deliver a part of the initialization data which may be possibly represented in separate MSDL files. Ref. [7] discusses the necessity to merge this initialization data. The merged initialization data will be used to initialize both C2IS and Simulations. The merging process can be a C2SIM service, or it can be a totally separate service since this is needed also for federations with no SIMC2 environment. Two other issues i.r.t. simulation control are mentioned in the paper: **multi-level initialization** and **time synchronization** between C2IS and the simulation environment. The entity level at which a simulation environment provides data may be too low for a C2IS, and needs to be aggregated first to become useful for initialization of a C2IS. With regard to time synchronization, it may be possible for C2IS to receive a report in the future from the simulation environment. Therefore, there should be some form of time management between simulation environment and C2IS, as is also discussed in Ref. [4].

A.3.4 Interface Monitoring and Control

C2-Simulation Interface monitoring and control concerns functionality to monitor the status of the interface and all of the systems that are connected to interface, and functionality to control the interface and connected systems. For example, ensuring that systems connect to or disconnect from the interface in an orderly way.

Examples of such functionality can be found in Ref. [16]. This paper discusses **a web-based coordination system** for MSDL/C-BML Coalitions. A Status Monitoring and Control system (SMC) provides the means of displaying to all system operators the status of each participating system, along with a "Master Controller" capability that can provide coordinated direction to the systems, either through their human operators or, through web services interfaced directly to the software systems. The SMC assumes the operation will take place in a sequence of well-understood phases in response to the Master Controller inputs. As noted above, not all systems will necessarily display each of these phases, but SMC is capable of displaying each phase for every client system. The phases are: Stopped, Initializing (i.e., is participating in process to generate and ingest aggregated coalition MSDL), Ready (i.e., has completed generating and ingesting coalition MSDL), Running, Paused.

Refs. [17] and [18] discuss functionality to **support the initialization** of client systems with an aggregated MSDL file. The SBML Server is used to aggregate individual and client provided MSDL documents. The Status Monitoring and Control system (described in the previous paragraph) is used to notify client systems when the aggregated MSDL document is available. The MSDL file may also be updated by client systems once the exercise has started, and other client systems will be notified as updates are available.

System initialization is also discussed in Ref. [10] using a Battlebook (see Section A.3.3).

In Ref. [19] a CBML-HLA gateway is described to enable the interoperability between a CBMS server and an HLA federation. The gateway manages the connection on the two sides through a graphical user interface which provides a visibility on current and past activities, i.e., **status of the connection** and **journal log of events**. This gateway can be viewed as a C2-Simulation Interface, with interface monitoring and control functionality.

A.3.5 Security

Security concerns functionality to secure the data (and access to data) that is received, stored, processed, and transmitted. No papers i.r.t. C2-Simulation interfaces were found on specifically this topic, but obviously this topic is important, e.g., only authorized systems should be allowed to connect to the C2-Simulation Interface; and only authorized systems should be allowed to send or receive data through the interface. However, in training mode, C2 Systems and simulation systems are typically connected in a (protected) VPN where security is a matter of trusting partners.

A.4 SCOPE AND USE CASES

The main purpose of this document is to present a Reference Architecture for the C2SIM Integration Platform, i.e., the interface between C2 Information System and Simulation System. What a reference architecture entails is described in Section A.1.

Use cases describe the interaction of actors (which can be either human users or systems) with a system in order to provide an observable result of value for the initiating actor. Therefore, in order to clearly describe the use cases, it is important to clearly define the scope of the system under consideration.

This document's scope is the C2SIM Integration Platform and the users of this system are the C2 Information Systems (C2IS) and Simulation Systems. However, within MSG-145 more use cases have been considered which are of a different level because in these use cases the system under consideration is a different system, namely the *C2SIM environment*, i.e., the system of systems containing the C2IS, the C2SIM Integration Platform system and the Simulation Systems. The users of this system of systems are the users of the C2IS and Simulation Systems and in case the C2SIM environment is used for training, also the training staff.

Therefore in order to avoid confusion, we focus in this document on the use cases for the C2SIM Integration Platform as described in Section A.4.1. For reference purposes, Section A.4.1 also gives some use cases which have been defined within MSG-145 for the C2SIM environment.

A.4.1 C2SIM Integration Platform Scope and Use Cases

This section discusses the use cases for the C2SIM Integration Platform that takes care of the exchange of data between C2 Information System and Simulation System in accordance with interface agreements and standards. These use cases are based on the C2SIM literature discussed earlier in Section A.3.

We distinguish two modes of use: *training mode* and *decision support* mode. At a high level, both modes will have similar interactions. In training mode we have a C2 Information System, a Simulation System and a Training Staff System interacting with the C2SIM Integration Platform. Decision support mode can have many variants, ranging from a single planner using his C2IS to a situation where many players are involved to do e.g., mission rehearsal.

For the training mode, we distinguish the following actors:

- C2 Information System(s) (C2IS) of the Training Audience (the trainees);
- Training Staff System(s):
  - C2IS for HICON: plays the role of the trainees' commanders.
  - C2IS for FLANCON: The Flanking (Neighbouring) Forces of the Trainees.
  - C2IS for LOCON: provides the interface between the TA and the simulation. LOCON receives orders sent by the TA and translates them into commands for the simulated forces. In addition, LOCON dynamically reports simulation results to the TA.
  - C2IS for OPFOR: plays the role of the enemy during the training exercise.
  - C2SIM environment control system.
  - WHITE-CELL system for role players that play all incidents or events that are not handled by the simulation system.
  - EXCON system, e.g., for execution control.
- The Simulation System(s).

The system boundary of the C2SIM Integration Platform is illustrated in Figure A-5 where the C2 Information System and Simulation System from Figure A-1 are abstracted into single systems.

In Figure A-6 we present a high level overview of use cases and actors for the C2SIM Integration Platform. Each use case can be further expanded into sub-use cases as needed, however a complete use case analysis is not in the scope of this study. For instance, initialization is not included in this high level overview. The actors in Figure A-6 are all denoted as systems, operated by e.g., training staff or C2 operators. We also assume that the Training Staff System can use specialized simulation control functions.

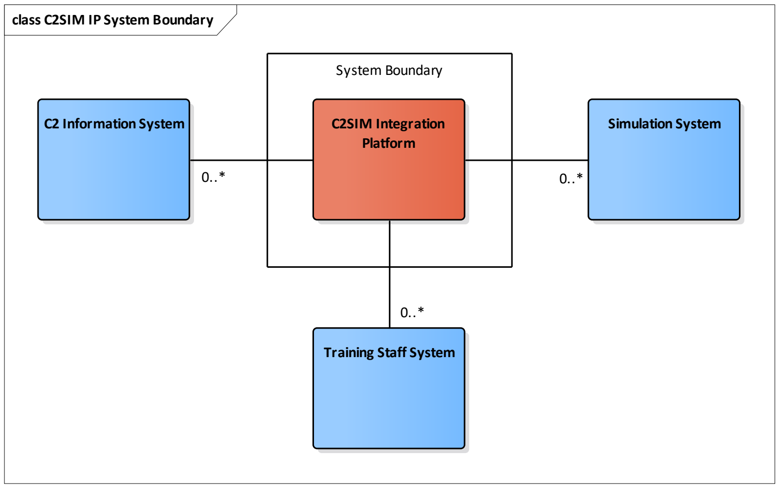

Figure A-5: System Boundary of C2SIM Integration Platform.

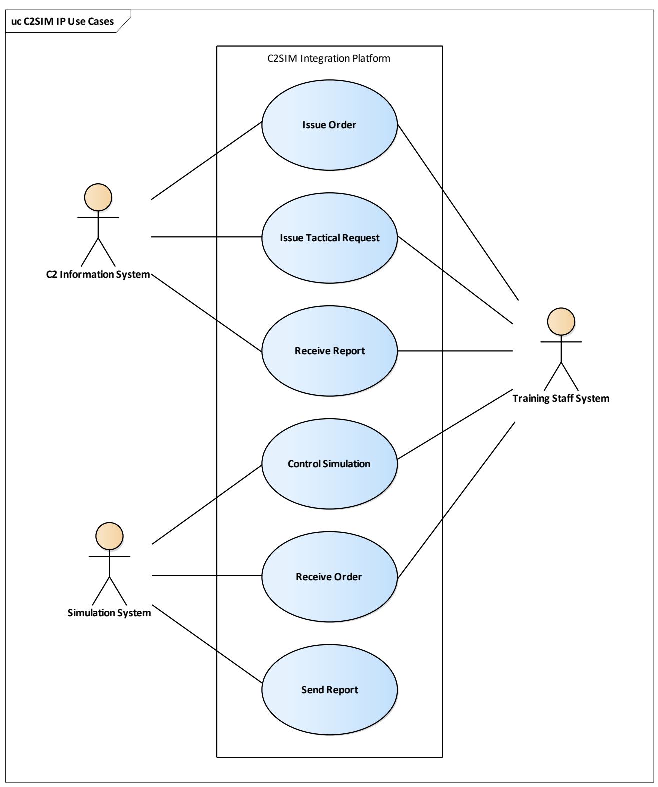

Figure A-6: User Interactions with the C2SIM Integration Platform for the Training Mode.

Note that this overview covers both modes; training mode as well as decision support mode. Obviously, depending on the mode, some users may not be present. For instance in the decision support mode and sometimes even for the training mode, a training staff system will not be present.

The use cases are summarized below. Note that the use cases are given for the training mode. The actors can differ for the decision support mode but the use cases will be similar:

- **Actor = C2 Information System or Training Staff System.**
  - **Issue order:** The C2IS issues an order to the C2SIM Integration Platform where it is stored and can be combined with orders coming from other C2IS.
  - **Issue tactical request:** a request (e.g., a Call for Fire) is sent by the C2IS to the C2SIM Integration Platform.
  - **Receive report:** a report is received from the C2SIM Integration Platform (that originated in a simulator). Note that the rate at which orders are received must be in line with the information demand of the C2IS and the rate at which the reports are sent to the C2SIM Integration Platform.
- **Actor = Training Staff System.**
  - **Issue log request:** The Training Staff System sends a log request to the C2SIM Integration Platform which will then log orders and reports to enable replay services.
  - **Issue replay request:** The Training Staff System sends a replay request to the C2SIM Integration Platform.
- **Actor = Simulation System or Training Staff System.**
  - **Control Simulation:** can consist of:
    - **Initialize simulation:** The Training Staff System issues initialization information (MSDL) to the C2SIM Integration Platform. Note that several C2IS can send (partial) initialization information which has to be merged in the C2SIM Integration Platform.
    - **Start simulation:** The Training Staff System sends a "start simulation" command to the C2SIM Integration Platform which issues it to the simulation.
    - **Stop simulation:** The Training Staff System sends a "stop simulation" command to the C2SIM Integration Platform which issues it to the simulation.
    - **Pause simulation:** The Training Staff System sends a "pause simulation" command to the C2SIM Integration Platform which issues it to the simulation.
  - **Receive order:** an order (that originated in C2IS) is received by the simulation from the C2SIM Integration Platform.
  - **Send report:** the simulation issues a report to the C2SIM Integration Platform.

A.5 FIRST STEP TOWARD A REFERENCE ARCHITECTURE

The literature review yielded common functionality that was identified in several papers and specific C2-Simulation Interface solutions. The next step is to transform the common functionality into a reference architecture and so-called architecture building blocks for any C2SIM Integration Platform solution.

A.5.1 Architecture Concepts

This section introduces the main architecture concepts for describing the architecture of the C2SIM Integration Platform. Figure A-7 shows some of the main architecture concepts and the relationships between them, from the conceptual model of architecture description in IEEE 42010-2011 [20]. Re-iterating some of the concepts in the conceptual model:

- Every **system** exhibits an **architecture.**
- An **architecture description** identifies a **system** and expresses an **architecture.**

In this context, an architecture description is a work product (a document), but an architecture is abstract, consisting of concepts and attributes.

An architecture can be described at different levels of abstraction. Typically, the term *reference architecture* is used for a more abstract form of architecture. A reference architecture generally provides guidelines and requirements to be used for the development of a *solution architecture*. There can be several solution architectures arising or being instantiated from a single reference architecture. When an architecture follows the guidelines and requirements from the reference architecture we say that the architecture is *instantiated* from the reference architecture, see Figure A-8.

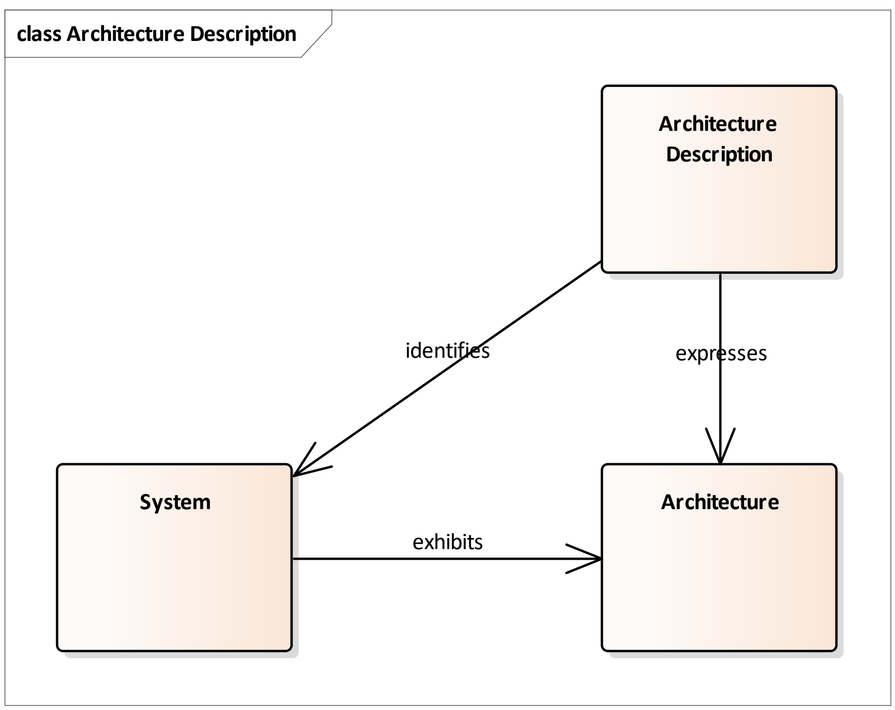

Figure A-7: Architecture Description.

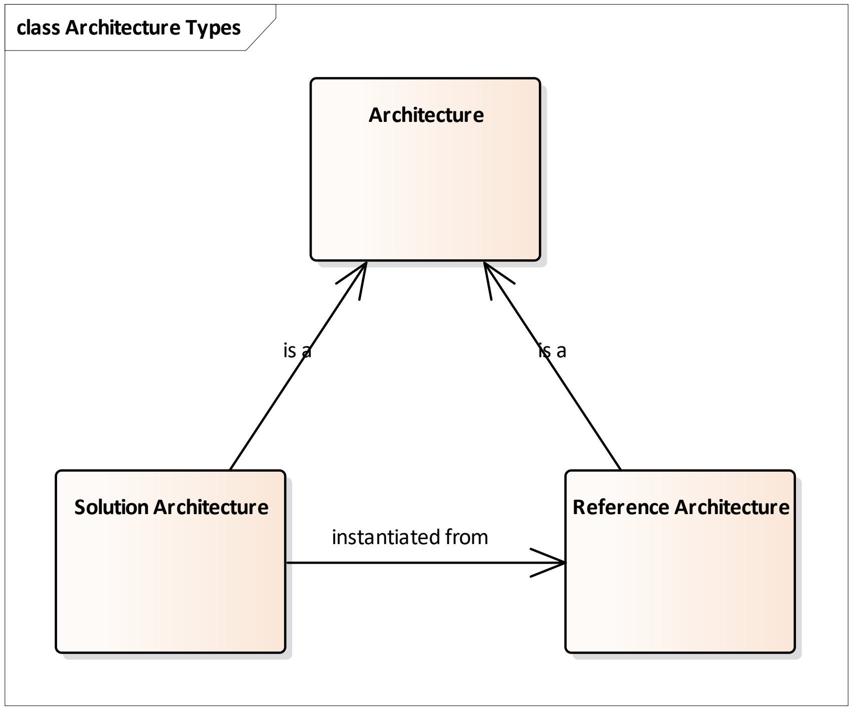

Figure A-8: Types of Architecture.

Table A-1 provides an example of the architecture concepts, using Mark's house as the system of interest.

Table A-1: Example of an Architecture Concept.

Element	Example
Solution (or solution implementation)	Mark's house, at address xyz.
Solution Architecture	The architecture of Mark's house; properties are for example size, color, building materials.
Solution Architecture Description	Documents with drawings that describe the architecture of Mark's house; the description provides exact information on e.g., sizes of rooms, windows, door positions, electricity wiring, etc. These documents have been created by the architect that was hired by Mark.
Reference System	The standard model house.
Reference Architecture	A standard model house, with properties such as standard materials, reference energy-efficiency, standard sizes and layout; the architect uses the reference architecture as a standard model for the development of the architecture for Mark's house.
Reference Architecture Description	Documents with drawings that describe the architecture of the standard model house, with constraints and requirements that will apply to the actual houses that will be developed from it.

The concepts used to describe the Reference Architecture for the C2SIM Integration Platform are shown in Figure A-9. These concepts are derived from the MSaaS Reference Architecture [21].

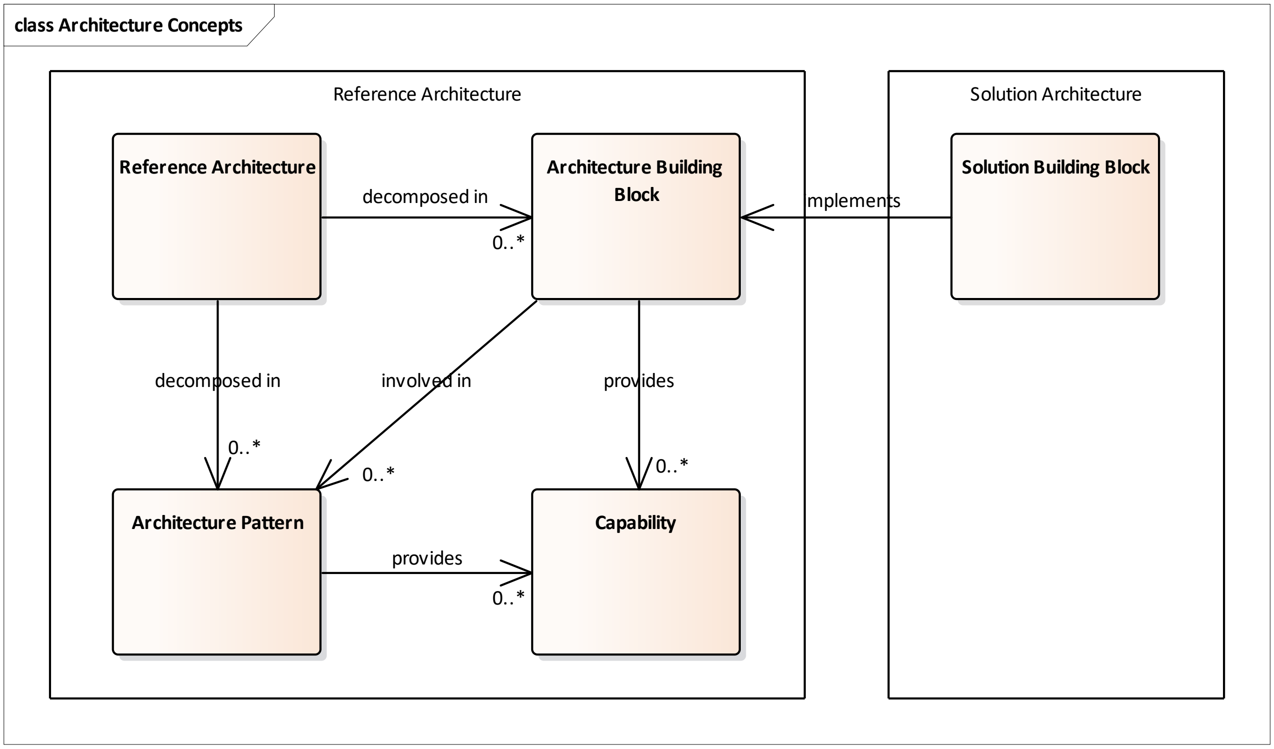

Figure A-9: Architecture Concepts.

In Figure A-9 the Reference Architecture is decomposed into *Architecture Building Blocks* and *Architecture Patterns*. A *Capability* is an ability that an Architecture Building Block or Architecture Pattern possesses and is expressed in terms of requirements related to the Architecture Building Block or Architecture Pattern. A *Solution Building Block* represents components that will be used to implement an Architecture Building Block.

An Architecture Building Block represents a component of the reference architecture and describes a logical aspect of the overall architecture. Attributes of an Architecture Building Block are:

- Name of the architecture building block;
- Description of the architecture building block;
- Requirements associated with the architecture building block, representing capabilities;
- Applicable standards;
- Related architectural patterns; and
- Related enabling technology.

An *Architecture Pattern* shows how Architecture Building Blocks may be combined, how they interact with each other, and what information is generally exchanged. Similar to an Architecture Building Block a pattern provides capabilities, expressed in the form of requirements. The architectural patterns serve as reference for a Solution Architecture. Attributes of an Architectural Pattern are:

- Name of the pattern;
- Description of the problem that the pattern helps to solve;
- Description of how the pattern provides a solution to the problem; and
- Illustrations to help describe the pattern.

To continue the example of Mark's house, Architecture Build Blocks and Architectural Patterns for the Standard Model House (the Reference Architecture) are given in Table A-2.

Table A-2: Example of Architecture Build Blocks and Architectural Patterns.

Element	Example
Architecture Building Block	The architect has the following elements in the standard model house. For each element there might be certain requirements, constraints or building standards to follow: • Kitchen; • Bed room; • Living room; • Porch; • Bath room; • Toilet; • Hallway; • Roof; and • Electricity and wiring.
Architectural Pattern	The architect has a set of standard patterns to arrange the elements in the model house, for example patterns where: • Toilet is next to Hallway; • House with one Toilet; • House with two Toilets; and • Bedrooms are on the back of the house. Each pattern may have associated requirements or constraints, e.g., if the "two toilet pattern" is used, then the kitchen must be at the side of the house.

A.5.2 NATO C3 Taxonomy and MSaaS Reference Architecture

The C2SIM IP RA uses both the NATO C3 Taxonomy [22] and the MSaaS Reference Architecture from NATO MSG-136 [2] as a source for Architecture Building Blocks and Architecture Patterns. We assume that the reader already has basic knowledge on the NATO C3 Taxonomy and we restrict ourselves to a brief overview below.

The NATO C3 Taxonomy is a library for NATO's Consultation, Command and Control (C3). Figure A-10 shows the C3 Taxonomy's top-level capabilities.

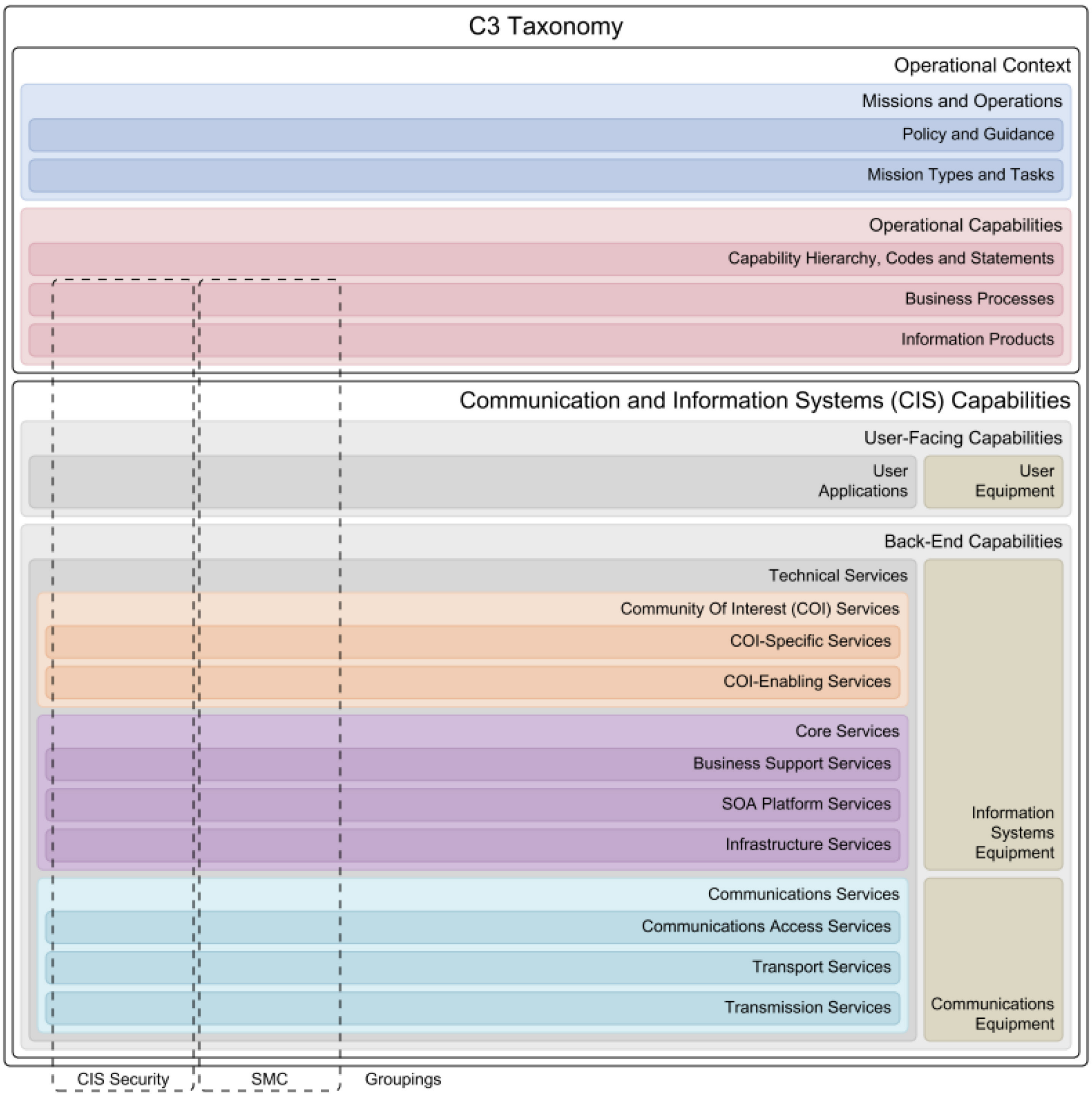

Figure A-10: NATO C3 Taxonomy – Top-Level View.

The capabilities are grouped into Missions and Operations, Operational Capabilities, User-Facing Capabilities, and Back-End Capabilities. Each group of capabilities is further decomposed into additional levels of capabilities, such as Business Processes (at the defence operational level), User Applications, Community of Interest (COI) Services, Core Services and Communications Services, and so on. Capabilities that are interesting for the C2SIM Integration Platform Reference Architecture are mostly found under the SOA Platform Services. For example, Message-Oriented Middleware Services, Mediation Services, and Platform CIS Security Services.

The MSaaS Reference Architecture defines extensions to the NATO C3 Taxonomy in relation to M&S as a Service. In particular it defines several extensions for the COI Specific Services and COI Enabling Services, such as Simulation Control Services, Simulation Scenario Services, M&S Repository Services, and M&S Message-Oriented Middleware Services. The name for each extension is prefixed with the word M&S to emphasize the M&S focus of the capability. These (proposed) extensions are not yet reflected in the current version of the NATO C3 Taxonomy, but can be found in the MSG-136 MSaaS Reference Architecture.

The NATO C3 Taxonomy uses so-called *perspectives* to present a coherent or related set of capabilities for a particular domain of interest or application area. A perspective takes capabilities from several places in the taxonomy and puts these in context of each other. A perspective may cover Business Processes, Information Products, CIS Capabilities, etc. For example, there are perspectives for CIS Security, Command and Control, Logistics, and Education and Training.

Note that in the C3 Taxonomy the User Applications and Technical Services are called “layers”, and the capabilities below these are called “categories”. In NATO MSG-136 both of these are called “Architecture Building Blocks” (ABBs). In this document we will follow the MSG-136 architecture concepts, i.e., ABB for both layer and category. We also follow the naming scheme of the NATO C3 Taxonomy.

A.5.3 C2SIM Integration Platform ABBs

This section lists the Architecture Building Blocks (ABBs) of the C2SIM IP RA. Where possible ABBs are linked in from the NATO C3 Taxonomy and the M&S extensions defined NATO MSG-136. An overview is provided in Figure A-11.

The color coding of the ABBs is conform the NATO C3 Taxonomy. For example, the Core Services have a purple color, and the COI Services an orange color.

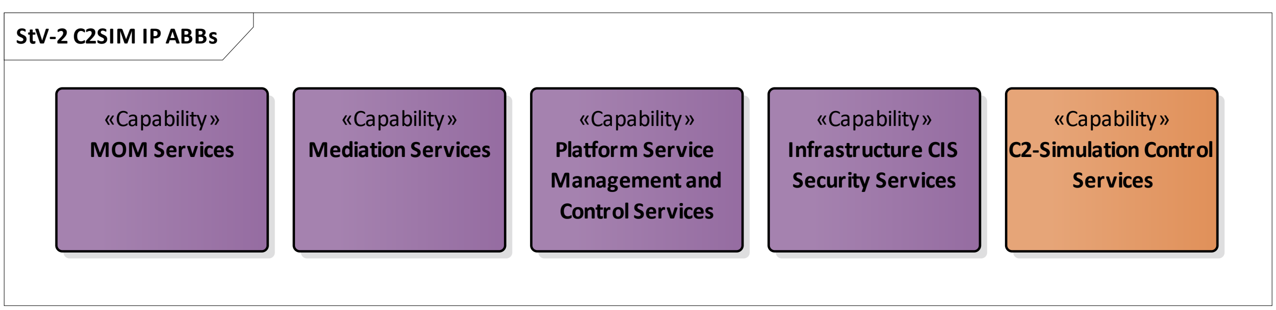

Figure A-11: C2SIM IP ABBs.

A.5.3.1 Message-Oriented Middleware Services

This ABB corresponds with the Message-Oriented Middleware (MOM) Services category in the NATO C3 Taxonomy.

A.5.3.1.1 Description

The NATO C3 Taxonomy has the following description:

> *The Message-Oriented Middleware Services provide functionality to support the exchange of messages (data structures) between data producer and consumer services, independent of the message format (XML, binary, etc.) and content.*
>
> *Message-Oriented Middleware Services support different models of message exchange (direct, brokered, queues), exchange patterns (request/response, publish/subscribe, solicit response (polling for response), and for fire and forget), topologies (one-to-one, one-to-many) and modes of delivery (synchronous, asynchronous, long running). They also provide the support for routing, addressing, and caching.*

The Message-Oriented Middleware (MOM) Services provide the capabilities to interconnect C2 Information Systems, Simulation Systems and Training Staff Systems. A commonly used name for MOM Services is *Enterprise Service Bus* (ESB). An ESB enables the loose coupling of software components (called *services*) that are expected to be independently deployed, running, heterogeneous, and disparate within a network [22].

The MOM Services have several sub-capabilities, which are described in more detail in the NATO C3 Taxonomy:

- Direct Messaging Services: provide point to point messaging services;
- Message Brokering Services: act as intermediary between Message Publishers and Message Consumers;
- Message Routing Services: dynamically route messages at run-time based on different criteria;
- Message Proxying Services: act as an intermediary for other services;
- Message Queueing Services: provide message queues as intermediary buffers; and
- Message Caching Services: conditionally store messages sent between producers and consumers.

In order to connect a Simulation System to the MOM Services, the Simulation System should provide a designated Simulation Service that interacts with the MOM Services. Note that the MOM Services mentioned here are different from the M&S MOM Services defined in the MSaaS Reference Architecture. The latter is used to integrate Simulation Systems or services in a simulation environment, which is not in the scope of the C2SIM Integration Platform.

A.5.3.1.2 Requirements

The following requirements from the NATO C3 Taxonomy apply to MOM Services (Table A-3 and Table A-4) The requirements related to the sub-capabilities of the MOM Services are not listed. See NATO C3 Taxonomy for these requirements.

Table A-3: Functional Requirements Applying to MOM Services.

Function Name	Requirements (The Message-Oriented Middleware Services Shall:)
Acquire Information	• Provide the means to organize acquired information into operationally defined topics.
Disseminate Information	• Provide the means to provide acquired information according to operationally defined topics. • Provide the means to disseminate acquired information to all echelons within the chain of command. • Provide the means to disseminate acquired information across theatre and reach-back facilities.
Customize Dissemination	• Provide the means to disseminate a filtered view of the acquired information as defined by a specific community of interest.
Manage Information Flows	• Provide the means to augment information as it propagates from provider to consumer. • Provide the means to filter information as it propagates from provider to consumer. • Provide the means to modify information as it propagates from provider to consumer. • Provide the means to combine information as it propagates from provider to consumer. • Provide the means to delete information as it propagates from provider to consumer.
Share Information	• Provide the means to share information between physical locations. • Provide the means to share information between services. • Provide the means to share information between services and consumers. • Support the exchange of information across domains (network technologies and topologies).
Manage Endpoints	• Associate an information source with an endpoint. • Associate an information sink with an endpoint. • Support the dynamic creation of endpoints. • Support the dynamic modification of endpoints. • Support the dynamic removal of endpoints. • Support endpoints that interface to a serial communications device. • Support endpoint that interface with a network device. • Provide the means to convert the information received on an endpoint to a stream of information. • Provide the means of providing a stream of information to an endpoint. • Provide the means to logically connect two endpoints for the purpose of establishing information flow from the producer to the consumer. • Provide the means to maintain synchronization between two endpoints.

Table A-4: Non-Functional Requirements Applying to MOM Services.

Requirement Type	Requirements (The Message-Oriented Middleware Services Shall:)
Manage Endpoints	• Support guaranteed unique message delivery avoiding message duplication. • Support guaranteed order of message delivery. • Support message delivery prioritization/precedence. • Be able to scale up and/or down in order to maintain required Quality of Service. • Support multiple levels of message delivery reliability (best effort, guaranteed, etc.). • Shall provide the means to automatically re-establish information flows after network disruption.

A.5.3.2 Mediation Services

This ABB corresponds with the Mediation Services capability in the NATO C3 Taxonomy.

A.5.3.2.1 Description

The NATO C3 Taxonomy has the following description:

> *The Mediation Services provide a middle layer between incompatible producers of information and consumers of information. Mediation Services process the data of the information producer and transform it into a representation which is understandable for the consumer. In doing so Mediation Services bridge the gap between both parties, enabling interaction between them which has not been possible beforehand.*

Mediation Services are used to directly couple a C2 Information System with a Simulation System. This is in contrast to MOM Services which can interconnect many systems or services. Note that solutions for MOM Services such as an ESB solution may also provide mediation capabilities. In general, Mediation Services receive data from a data producer and transform it into a representation that is understood by the consumer.

The Mediation Services have several sub-capabilities, which are described in more detail in the NATO C3 Taxonomy:

- Protocol Transformation Services: mediate between communication parties by adjusting the way in which data is exchanged between both parties (e.g., HTTP – HTTPS transformation).
- Data Format Transformation Services: support the encoding of information in different formats (e.g., XML – JSON transformation).

Note that the MSaaS Reference Architecture also defines M&S Mediation Services. This capability belongs to the scope of the simulation environment and provides the means to connect or integrate simulation components or services within a simulation environment.

A.5.3.2.2 Requirements

The following requirements from the NATO C3 Taxonomy apply to Mediation Services (Table A-5, Table A-6). The requirements for the sub-capabilities are not listed. See NATO C3 Taxonomy for these requirements.

Table A-5: Functional Requirements Applying to Mediation Services.

Function Name	Requirements (The Mediation Services Shall:)
Manage Transformations	• Provide the means to expose a transformation as a service. • Provide the means to activate a transformation service. • Provide the means to deactivate a transformation service.
Transform Information	• Take data in the format and protocol used by an information producer, transform the data, and create data in another format that can be understood and communicated to the intended information consumer. • Guarantee that messages that are communicated between producer and consumer endpoints always comply to all policies which are relevant for the communication. • Provide the information which is needed to perform the transformation, i.e., the underlying semantic models, either explicitly at run-time, or implicitly in the implementation of the service at design time.

Table A-6: Non-Functional Requirements Applying to Mediation Services.

Requirement Type	Requirements (The Mediation Services Shall:)
	• Preserve the information that is exchanged between a producer and a consumer in the sense that the information remains consistent and does not become contradictory. • Not introduce inconsistencies in the data in the cases where the transformation cannot preserve all the original information. • Respect the non-functional requirements of the services between it mediates.

A.5.3.3 Platform Service Management and Control Services

This ABB corresponds with the Platform SMC capability in the NATO C3 Taxonomy.

A.5.3.3.1 Description

The NATO C3 Taxonomy has the following description:

> *The Platform Service Management and Control (SMC) Services provide a suite of capabilities needed to ensure that platform services are up and running, accessible and available to users, protected and secure, and that they are operating and performing within agreed upon parameters. They also provide the necessary means to implement and enforce SMC policies at the platform level.*

The SMC Services provide the means to manage and control the (components/services of the) C2SIM Integration Platform, and monitor the health and welfare of the C2SIM Integration Platform. This concerns monitoring services within the C2SIM Integration Platform, as well as monitoring what systems are connected to the C2SIM Integration Platform (i.e., C2 Information System, Simulation Systems, and Training Systems).

The SMC Services have several sub-capabilities, which are described in more detail in the NATO C3 Taxonomy:

- Policy Enforcement Services: enforce technical and business policies related to performance, quality of service, agreed service levels, and ensures compliance.
- Service Discovery Services: enable a requester to discover a target service that matches certain functional and non-functional requirements.
- Platform Logging Services: provide facilities for capturing, filtering and writing information about calls between services in the Platform.
- Platform Monitoring Services: provide information on the actual utilization and performance of monitored Platform Services.
- Platform Metering Services: measures platform resource utilization.

Although all these capabilities are relevant, the most applicable sub-capabilities for the C2SIM Integration Platform are Logging, Monitoring, and Metering.

A.5.3.3.2 Requirements

The following requirements from the NATO C3 Taxonomy apply to SMC Services (Table A-7, Table A-8, Table A-9). See NATO C3 Taxonomy for these requirements.

Table A-7: Functional Requirements Applying to Logging.

Function Name	Requirements (The Platform Logging Services Shall:)
Log Service Calls	• Provide functionality to log summary information about messages that constitute service calls. • Include logged attributes such as: Message time-stamp; Message source and target address; URL requested; Service requested; Operation requested; Request size; and Unique request id (extracted from the message or automatically generated by the Logging Services). • Provide functionality to log attributes extracted from the message payload. • Provide the means to configure the message payload attributes to include in the log. • Provide functionality to log selectively whole messages based on pre-configured criteria or filter (e.g., policy based).
Pair Service Calls	• Provide functionality for pairing service requests with their responses (or faults).

Table A-8: Functional Requirements Applying to Monitoring.

Function Name	Requirements (The Platform Monitoring Services Shall:)
Monitor Performance	• Provide functionality to monitor service performance. • Provide functionality to identify stalled processes or those that have fallen outside of normal performance parameters.
Monitor Faults	• Provide functionality to monitor service faults and exceptions.
Monitor Availability	• Provide functionality to monitor service availability.
Monitor Messaging	• Provide functionality to monitor service messages and service calls traffic.
Monitor Services	• Provide functionality for real time monitoring of individual services. • Be configurable to allow monitoring of required metrics (e.g., response time, throughput, fault rates, idle time, rejected messages, etc).
Raise Alerts	• Provide functionality to raise alerts if monitored parameters (e.g., performance, number of exceptions) exceed a configurable threshold.
Monitor End-to-End Processes	• Provide functionality for real time monitoring of currently processes against expected metrics. • Provide functionality to drill down from process monitoring to individual service monitoring.

Table A-9: Functional Requirements Applying to Metering.

Function Name	Requirements (The Platform Metering Services Shall:)
Aggregate Measures	• Allow to aggregate collected measures for given user/tenant. • Allow to aggregate collected measures over different periods of time (e.g., day, month, year).
Meter Utilization	• Measure utilization of various Platform resources over specific periods of times.
Provide Measures	• Make collected measures available for retrieval.
Archive Measures	• Archive collected measures over long period of time to enable resource utilization trend analysis.

A.5.3.4 Infrastructure CIS Security Services

This ABB corresponds with the Infrastructure CIS Security Services capability in the NATO C3 Taxonomy.

5.3.4.1 Description

The NATO C3 Taxonomy has the following description:

> *The Infrastructure CIS Security Services provide the necessary means to implement and enforce CIS Security policies at the infrastructure level.*

This capability concerns security at the platform infrastructure level, and covers topics such as authentication, authorization, and certificates. This capability provides the means to protect access the C2SIM Integration Platform, i.e., only authenticated/authorized C2 Information Systems should be allowed to connect to the C2SIM Integration Platform. Some ESB solutions provide MOM capabilities as well as security capabilities.

This capability has several sub-capabilities, which are described in more detail in the NATO C3 Taxonomy. The most relevant sub-capabilities for the C2SIM Integration Platform are itemized below:

- Authentication Services: provide functionality to verify that a claimed identity is genuine and based on valid credentials.
- Authorization and Access Services: provide functionality to grant or deny access to services and data.

A.5.3.4.2 Requirements

The following requirements from the NATO C3 Taxonomy apply to the Infrastructure CIS Security Services (Table A-10, Table A-11). See NATO C3 Taxonomy for these requirements.

Table A-10: Functional Requirements Applying to Authentication.

Function Name	Requirements (The Authentication Services Shall:)
Validate Credentials	• Authenticate the identity of an entity accessing protected resources by validating the credentials of the entity. • Support multi-factor (multi-credential) entity authentication. • Provide the identity assurance level as specified for electronic transactions requiring authentication.
Validate Biometric Characteristics	• Capture and extract measurable, physical characteristics used to recognize the identity. • Compare and match physical characteristics to verify the claimed identity of an entity.
Manage Sessions	• Share identity data among multiple relying parties as a part of an authenticated user session (single sign-on functionality). • Support protocol translation for access to systems needing different authentication protocols. • Manage automatic time-outs and requests for re-authentication.
Federate Providers	• Establish a trust relationship between discrete digital identity providers that enables a relying party to accept credentials from an external identity provider in order to make access control decisions.

Table A-11: Functional Requirements Applying to Authorization and Access.

Function Name	Requirements (The Authorization and Access Services Shall:)
Enforce Policy	• Restrict access to specific systems or content in accordance with policy.
Retrieve Entity Attributes	• Acquire additional information not found in the authenticated entity credential that is required to make an access based decision.
Administer Policy	• Create, disseminate, modify, manage, and maintain hierarchical rule sets to control digital resource management, utilization, and protection in a standard policy exchange format.
Evaluate Policy	• Evaluate access control policies based on a variety of inputs.

A.5.3.5 C2SIM Control Services

The previous ABBs rely on general capabilities in the C3 Taxonomy, i.e., the SOA Platform Services and Infrastructure Services, whereas this capability is more specific to C2 and Simulation. There is currently no capability for specifically this ABB in the NATO C3 Taxonomy. It is current categorized under the COI Services (and hence the orange color).

A.5.3.5.1 Description

The C2-Simulation Control Services provide the capability to coordinate the initialization, execution, and termination of systems that are connected to the C2SIM Integration Platform. System is in this context a C2 Information System, Simulation System, or Training System.

Two modes of operation of the C2SIM Integration Platform are currently foreseen:

- Training mode: the simulation is performed by the simulation environment in wall-clock time; time and location-related information between simulation environment and C2 Information System are aligned.
- Decision support mode: the simulation is performed by the simulation environment in non-real time; time and location-related information in the simulation environment are decoupled from time and location-related information in the C2 Information System.

A.5.3.5.2 Requirements

The following requirements apply to the C2-Simulation Control Services (Table A-12).

Table A-12: Functional Requirements Applying to C2-Simulation Control Services.

Function Name	Requirements (The C2-Simulation Control Services Shall:)
Manage Modes	• Provide functionality to manage different modes of operation (**training mode, decision support mode**)
Initialization	• Provide functionality to coordinate the order in which systems may connect with each other.

Function Name	Requirements (The C2-Simulation Control Services Shall:)
Initialization (cont'd)	• Provide functionality to initialize C2 Information Systems with C2 data that is provided by Simulation Systems (**training mode**). • Provide functionality to initialize Simulation Systems with C2 data that is provided by C2 Information Systems (**decision support mode**).
Execution	• Provide functionality to manage execution states across C2 Information Systems and Simulation Systems. • Provide functionality to manage time across C2 Information Systems and Simulation Systems (**training mode**). • Provide functionality to manage checkpoints across C2 Information Systems and Simulation Systems (create, load) (**training mode**).
Termination	• Provide functionality to coordinate an orderly disconnect sequence of systems.

A.5.4 C2SIM Integration Platform APs

This section lists a few Architecture Patterns (APs). For each pattern a brief description is provided.

A.5.4.1 Mediation Pattern

This pattern illustrates how two systems can be connected via simple protocol conversion by the Mediation Services (e.g., STOMP / REST). Merely protocol conversion is quite idealistic because besides protocol conversion there are often data conversions that need to be done. Mediation also includes addition of missing data to messages or removal of unnecessary data from the messages (Figure A-12).

A.5.4.2 Initialization Pattern

This pattern shows how the C2-Simulation Control Services coordinate the connect sequence of systems. In training mode a possibility is that the Simulation System is running before any of the C2 Systems (e.g., to be able to provide initialization data to the C2 Systems). The C2-Simulation Control Services in such a case ensure that the C2 Systems start after the Simulation System. Figure A-13 illustrates a simple sequence of messages to accomplish this, but we are aware that further messages exchanges are needed for a more full-proof connect sequence. Note that it may also be the case that the C2 Systems initialize the simulation systems and thus need to be running before the simulation systems. An example of the latter was used in the German – French training exercise, see Ref. [18].

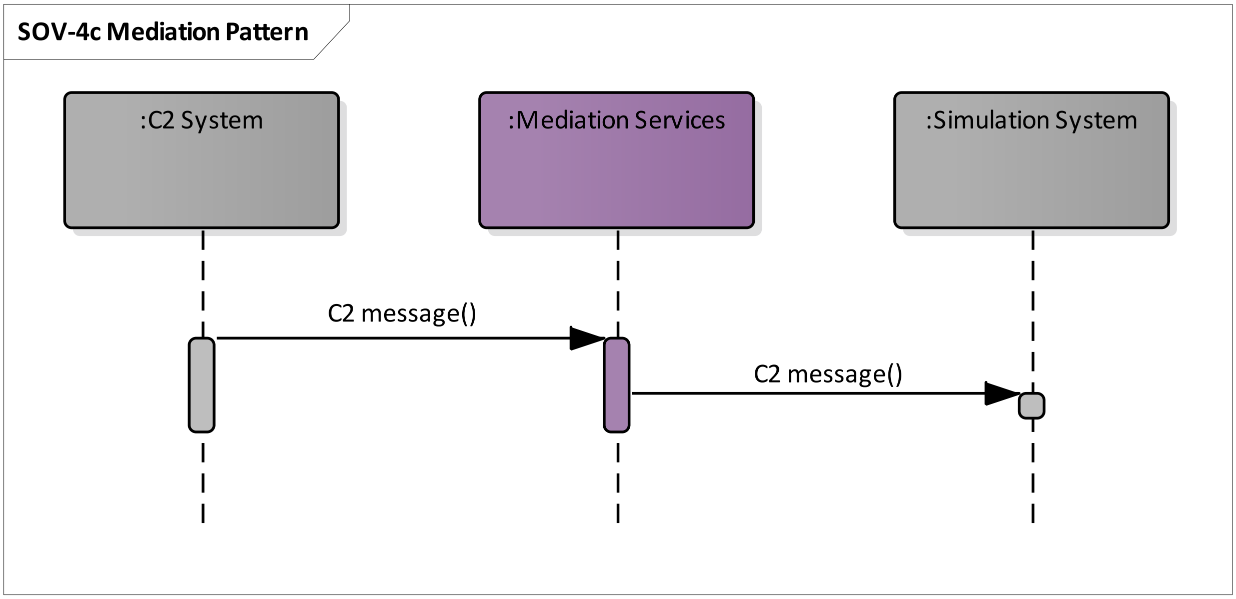

Figure A-12: Mediation Pattern.

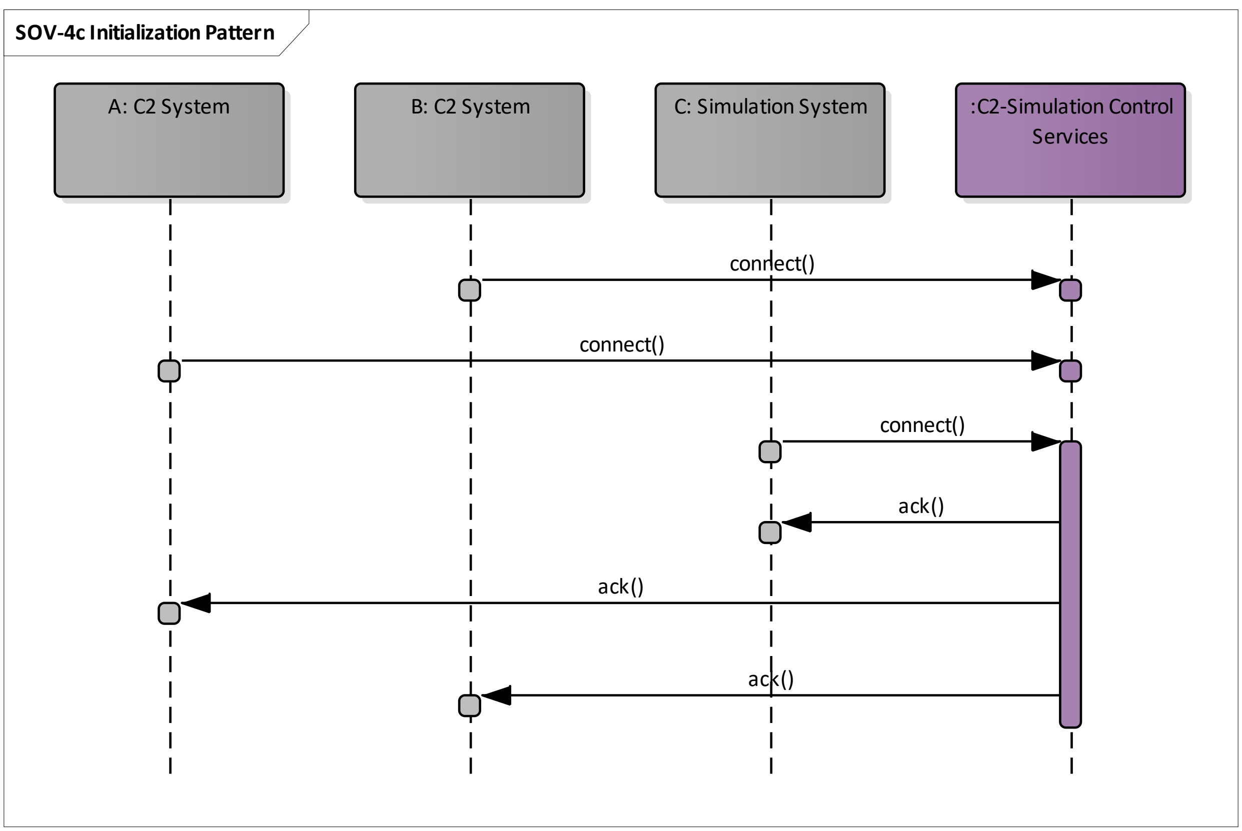

Figure A-13: Initialization Pattern.

A.5.4.3 C2SIM Interaction Pattern

For the interaction between C2 System and simulation environment a common pattern is to use a C2 Agent. This Agent translates C2 messages (C-BML) to Lower Level instructions (LLBML) for entity simulation and v.v. This pattern has been described in many papers.

Also note the system boundaries in Figure A-14 (see Section A.1 for a discussion on naming). The simulation environment provides the simulation capabilities, in this example an Agent (an implementation of Simulation Services), an HLA-RTI (an implementation of M&S MOM Services), and a CGF (again an implementation of Simulation Services). For more information about these ABBs, see the MSaaS Reference Architecture [21].

The Agent is also part of the C2SIM environment, and provides an interface to connect into the ESB (which is an implementation of the MOM Services).

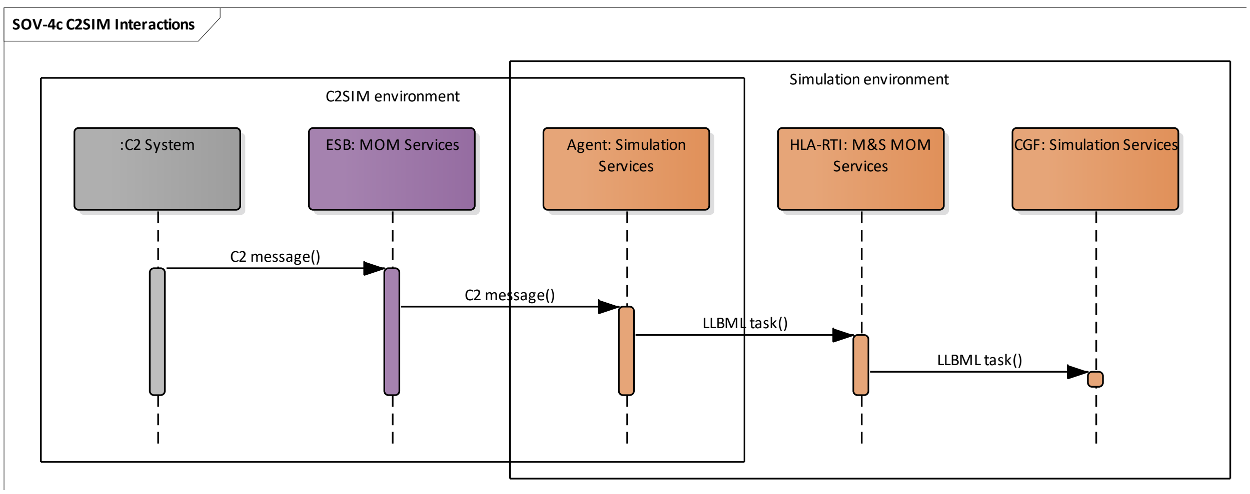

Figure A-14: C2SIM System Overview.

A.6 CONCLUDING REMARKS

The study started with the original need from MSG-085, namely that *a "reference architecture" for C2SIM interfaces should be developed to facilitate C2SIM environment design*. We have defined the scope of "C2-Simulation", where we distinguish between C2SIM Integration Platform and C2SIM Environment. We have focused on the C2SIM Integration Platform.

As a first step towards a reference architecture we performed the following tasks:

- A literature review with the aim to identify common functionality in technical solutions for C2-Simulation interfaces.
- Description of C2SIM scope and use cases.
- Definition of architecture concepts.
- Identification and description of C2SIM Architecture Building Blocks (ABBs) and Architecture Patterns (APs).

The identified ABBs and APs can be used as building blocks for developing C2SIM Integration Platform solutions. This can support the development since they provide a set of well-defined elements which can be chosen from. How precisely the selection and combination should take place possibly needs to be elaborated and guidelines to be developed.

The tasks were performed within a limited time and budget, so we could only address ABBs and APs to some degree. It is therefore advised to MSG-145 to verify and extend/improve the use cases, as well as the set of ABBs and APs identified. For instance, we have mainly taken into account the training mode in defining ABBs and APs but we foresee that looking deeper into the decision support mode may reveal more elements and patterns.

Furthermore, the C2SIM Reference Architecture development should stay in line with other current developments like the MSG-136 MSaaS Reference Architecture as well as the NATO C3 Taxonomy.

A.7 TERMINOLOGY

Term	Description
Architectural Pattern	Rules and guidelines for organizing Architecture Building Blocks.
Architecture Building Block	Represents a component of a reference architecture and describes a logical aspect of the overall architecture.
Solution Building Block	Represent a component of the solution that will be used to implement the required capability.

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[23] Enterprise_service_bus, Wikipedia, 2017. Available at: https://en.wikipedia.org/wiki/Enterprise_service_bus.

Annex B – 2019 MINI EXERCISE

B.1 OVERVIEW

The MSG-085 MiniEx (Section 4.2) was designed to test as many aspects of the C2SIM standard as possible in a credible coalition environment. The scenario was used previously in CWIX 2019 to provide an operationally relevant set of test cases. This Annex describes the operational scenario used in the MiniEx and how it was developed.

B.2 OPERATIONAL ASPECTS

The narrative for the main 2019 MiniEx scenario was developed by military Subject Matter Experts (SMEs) at NPS and ATEC in the US with individual vignettes contributed by SMEs in Germany, Italy and the UK. The MiniEx scenario was set in current times in the fictional Scandinavian country of Bogaland, see Figure B-1.

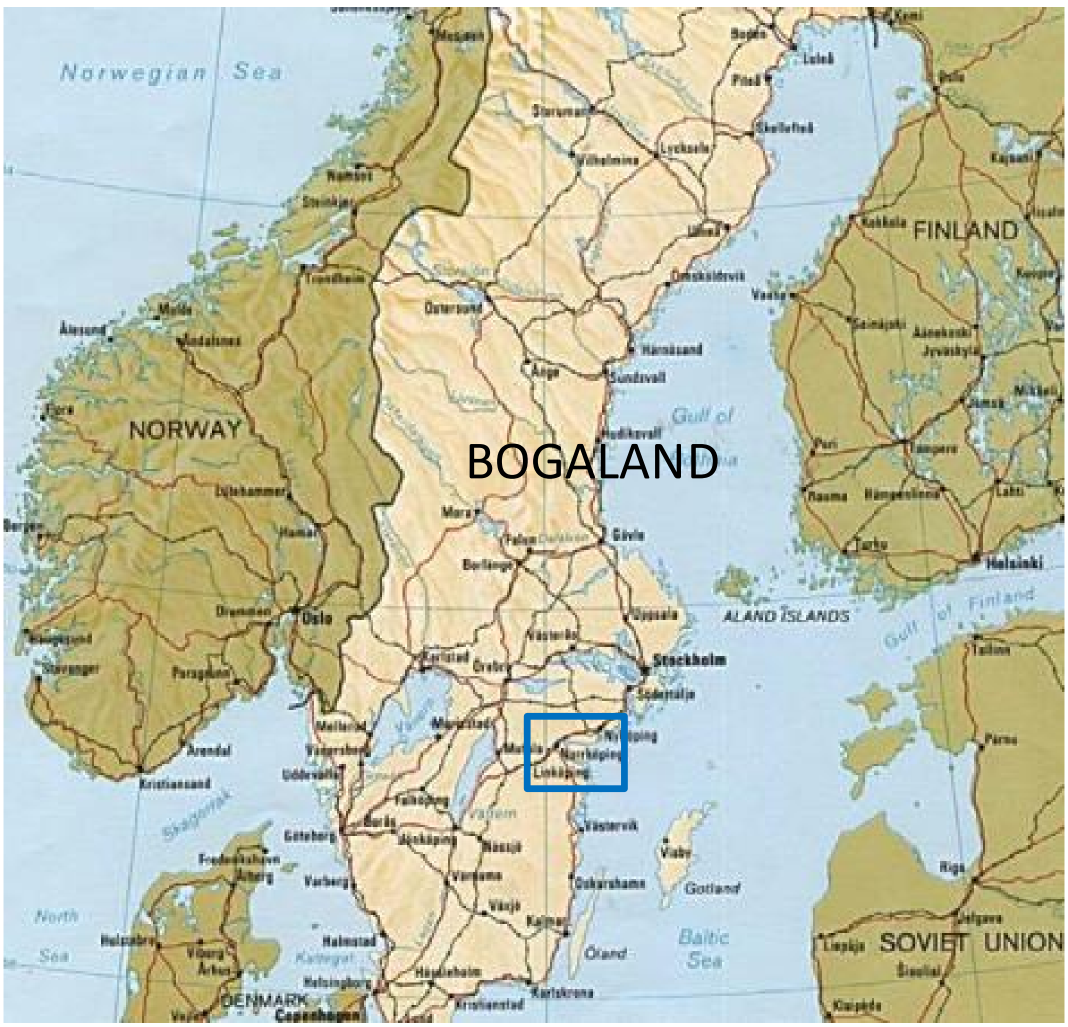

Figure B-1: Overview of MiniEx Situation.

B.3 SITUATION

These are the key points of the current situation in Bogaland:

- In 2018, NATO ground forces began deploying in Bogaland to assist the Bogaland government in countering the increasingly aggressive activities of the WASA, the indigenous people of the Norrköping region.
- The WASA are receiving assistance from external nation-states. Information Operations and aggressive military activities have been initiated using the WASA as a surrogate.
- The WASA have been expanding their presence across the region along Highway E4 from Linköping to Norrköping, with the intent to move into Stockholm.
- To begin operations, the WASA are using Braviken Bay for logistics operations. Additionally, they are seeking to create a new port at Oxelösund to begin their movement northward to Nyköping.
- As the WASA grows in strength, the Bogaland government has requested NATO support to stop WASA's extensive usage of Braviken Bay and counter their movement towards Stockholm along Highway E4 north of Linköping.
- Intelligence reports also suggest that WASA reinforcements and supplies maybe coming in via the Baltic Sea to ports vicinity of Oxelösund, Kolmarden, and Krokek.

Given these activities, NATO has been asked to prevent this influence in the region, violence against civilians, and its spread to Stockholm.

B.4 AREA OF OPERATIONS

Figure B-2 shows the Area Of Operations (AO).

The 1st Brigade Combat Team (BCT) operational boundaries are depicted in blue lines, with Bogaland's 3rd Infantry Battalion (BN) operating to the north and 4th Infantry BN operating to the south. Key urban locations are denoted with black circles throughout the AO. Main transportation corridors include Highways E4 and 53, and the Braviken Bay inlet.

The Airport Of Debarkation (APOD) is the Norrköping Airport. The 1st BCT command post has been established in a Forward Operating Base (FOB) near this airport.

B.5 MISSION AND COMMANDER'S INTENT

The mission and commander's intent were defined as follows.

B.5.1 Mission

"On order NATO Forces under command and control of 1BCT (US) conduct reconnaissance and combat operations within the 1BCT area of operations in support of the Bogaland forces and civilians to deter and defeat WASA forces' ability to establish operations in Stockholm."

Figure B-2: Area of Operations.

B.5.2 Commander's Intent

"I intend to initially gain intelligence on WASA organizational structure and intent through UAS reconnaissance within sector with emphasis on Highway E4 and the Braviken Bay. If attacked or fired upon, we will immediately transition into offensive combat operations. Our primary mission is to prevent WASA from establishing operations in the 1BCT sector that enable their movement towards Stockholm. My commander's Critical Information Requirements (CCIRs) will drive my decision making and determine 1BCT actions and level of force."

B.6 THE CONCEPT OF OPERATIONS

Figure B-3 shows the concept of operations for the main scenario. The key elements of which are as follows:

1) At H Hour, 1BCT launches 2 x UK UAS to conduct aerial reconnaissance of Highway E4 from Linköping to Norrköping, and 2 x IT UAS to conduct aerial reconnaissance of E4 from Norrköping to Nyköping; GE UAS BPT to support reconnaissance operations; AU, NZ, and US patrol boats BPT to conduct port reconnaissance of the Baltic Sea and Braviken Bay if maritime activity is identified by UAS.

2) Mission: identify any WASA activity in sector, Braviken Bay, or movement along E4, and escalation of hostile activities vicinity of NAI 1; O/O execute Operation Exodus.

3) CCIRs:

   - WASA use of force against civilians;
   - Downed UAS;
   - WASA use of force against NATO Forces;
   - WASA movement along E4;

- WASA maritime movement in Braviken Bay;
- Detection of chemical weapons; and
- WASA offensive cyber/EW activities.

4) A Cyberspace Electromagnetic Activities (CEMA) cell monitors social media and local news/blogs in sector.

Figure B-3: Concept of Operations.

B.7 THE MSEL

A Master Scenario Events List (MSEL) was created by the SME team in the form of a spreadsheet. The main sheets in the document covered the force structure, an event script and a more detailed tasking plan. The MSEL creation process was done in a fairly traditional way but with evolving C2SIM-enabled tools this could be achieved directly and more easily.

B.7.1 Force Structure

Figure B-4 shows part of the NATO blue force task organization as defined by the SMEs in the MSEL. Further details such as capabilities, weapon and sensor fits, dispositions, command structure, sub-unit compositions were also defined. These definitions were used to create C2SIM Initialization documents. Similar information was prepared to cover OpFOR and non-aligned actors.

Blue forces include a brigade level CEMA unit and this unit is simulated to detect and respond to WASA cyber activities.

Unit	Side	Size	Weapons
1BCT (USA IN)	BLUE	Brigade TF	Small Arms, AH-64, CH UAS, Patrol Boats
UAS 1 & 2 (UK)	BLUE	2	None
UAS 3 & 4 (ITA)	BLUE	2	None
UAS 5 & 6 (DEU)	BLUE	2	None
UGV (ITA)	BLUE	1	None
Maritime Patrol	BLUE	2 Boats (AUS) 1 Boat (NZL) 1 Boat (USA)	TBD
D/170th AV RGMT QRF (USA 4 x CH-47, 2 x MH-6)	BLUE	Company	Mix of M4 MH-6 (gu
C/102nd AV BN (USA AH-64)	BLUE	Company	30mm,
1/1BCT (USA IN) (Stryker)	BLUE	Battalion	Mix o
A/1/1BCT (USA IN)	BLUE	Company	Mix
B/1/1BCT (USA IN)	BLUE	Company	Mi
2ND IN BN (UK)	BLUE	Battalion	Mi
A/2nd IN BN (UK)	BLUE	Company	Mi
B/2nd IN BN (UK)	BLUE	Company	Mix
C/2nd IN BN (UK)	BLUE	Company	Mix
3RD IN BN (DEU)	BLUE	Battalion	Mix ot

Figure B-4: Friendly Order of Battle.

B.7.2 Event Script

Figure B-5 shows part of the event script taken from the MSEL document. Each row gives a narrative for each event, required actions for the different forces, who is responsible for providing the simulation and which simulator is to be used.

B.7.3 Tasking Plan

Figure B-6 shows a section of the tasking plan which assigns the events to specific sub-units or actors, e.g., named platoons; gives them the required C2SIM ActionTaskCode values; geographic information such as routes, destinations and objectives and timing information. The events are also mapped onto a set of CCIRs, information which the commander needs to support his decision making, etc.

Date	Planned Z-Time	H-Time	General Location	Event	BLUFOR	BLUFOR-SIM	BLUEFOR-TEAM	REDFOR	REDFOR-SIM	REDFOR-TEAM
		H HOUR	Linköping	Wheeled WASA REDFOR 4-vehicle convoy begins moving NE from 58.410828N, 15.621319E (vic Linkoping) along Highway E4; the BCT HQ is conducting zone reconnaissance with UAS in Zones 1 and 2	1 x UK UAS and 1 x IT UAS	JSAF	UK & MSCOE	Linkoping Cell; 4 x wheeled technical vehicles (small pick up trucks)	JSAF	GMU
		H to H+1	Linköping	UK INF company near Borg sets up blocking positions along E4 to intercept convoy moving towards them	B Coy UK IN BN	VRForces	UK	4 vehicle convoy continues moving along E4	JSAF	GMU
		H to H+1	Linköping	OPFOR convoy moving along E4 from Linkoping toward Norrkoping shoots down the UK UAS; BCT HQ launches German UAV to monitor crash site in Zone 1	1 x GE UAS	JSAF	UK	4 vehicle convoy shoots down UK UAS, collects wreckage, send pics to red cyber elements, and moves back to Linkoping	JSAF	GMU
		H to H+1	Norrköping	OPFOR begins posting to social media; BLUFOR conducts defensive cyber operations	BCT HQ Cyber Team	?	GMU	REDFOR cyber cell NorCC7 posts pics of wreckage to social media	JSAF	GMU
		H to H+1	Krokek	IT UAS observes escalating agression between WASA forces and civilians 58.676817N,16.369984E (vic Krokek)	1 x IT UAS recon in Zone 2; begins focus on area of tension vic NAI 1	JSAF	MSCOE	Company size red forces of light infantry from KroC6, wheeled vehicles, and small arms vic of 58.676817N,16.369984E (vic Krokek)	JSAF	GMU
		H to H+1	Linköping	IT UAS reports hostilites (shots fired) between civilians and REDFOR vic of 58.410828N, 15.621319E (vic Linköping)	BCT HQ orders execution of OP EXODUS to conduct NEO of civilians from area of hostile activities	verbal orders	UK	REDFOR from LinC3 vic 58.410828N, 15.621319E continue engaging with civilians	JSAF	GMU
		H+1 to H+2	Braviken Bay	BCT HQ orders maritime patrol of of Baltic sea, Braviken Bay, and Oxelsund port	2 x AU and 2 x NZ boats from port at Oxelosund; 1 x UK UAS moves to Zone 3	VRForces and JS	AU, NZ, and UK	One midsize cargo ship operating in Baltic Sea with 4 small transport boats moving between the cargo ship and Oxelosund port	JSAF (or VRForces?)	GMU
		H+1 to H+2	Linköping	US D/170th transports UK QRF and Recce Sections to HLS to secure HLS and Evacuation point for NEO vic 58.410828N, 15.621319E (this may require multiple trips). AH-64s provide fire support.	4 x CH-47s, C/2 UK IN (QRF), and Recce Sections, AH-64s.	JSAF (Aviation) and VRForces (Infantry)	UK	REDFOR from LinC3 vic 58.410828N, 15.621319E continue engaging with civilians	JSAF	GMU

Figure B-5: Event Script.

Simulation	ActionTask Code	ShortName	UNIT	ACTION	StartNorthing	StartEasting	StartN,E	EndNorthing	EndEasting	EndN,E	FROM	TO	PURPOSE
OneSAF	INIT	KroC6	Krokek Cell-6	Initial	58.676817	16.369984	58.676817, 16.369984	NA	NA	NA, NA	00:00	00:00	Preparing to receive 5 boats from
OneSAF	INIT	USBn1CoA	US Army Bn 1 CoA	Initial Position	58.648178	16.16817	58.648178,16.16817	NA	NA	NA, NA	00:00	00:00	In Company Assembly Area (AA) vic Jursla.
OneSAF	INIT	USBn1CoAp1	US Army Bn 1 CoA Plt 1	Initial Position	58.648178	16.16817	58.648178,16.16817	NA	NA	NA, NA	00:00	00:00	In Company Assembly Area (AA) vic Jursla.
OneSAF	INIT	USBn1CoAp2	US Army Bn 1 CoA Plt 2	Initial Position	58.648178	16.16817	58.648178,16.16817	NA	NA	NA, NA	00:00	00:00	In Company Assembly Area (AA) vic Jursla.
JSAF	INIT	USAQRF	D/170th AV RGMT QRF	Initial Position	58.586727	16.249418	58.586727, 16.249418	NA	NA	NA, NA	00:00	00:00	Norrköping Airport
JSAF	INIT	AH-64	C/102nd AV BN (USA AH-64)	Initial Position	58.586727	16.249418	58.586727, 16.249418	NA	NA	NA, NA	00:00	00:00	Norrköping Airport
OneSAF	MOVE	USBn1CoAp1	US Army Bn 1 CoA Plt 1	Move to Krokek	58.648178	16.16817	58.648178,16.16817	58.676817	16.369984	58.676817,16.369984	01:00	01:30	Move to Krokek
OneSAF	MOVE	USBn1CoAp2	US Army Bn 1 CoA Plt 2	Move to Krokek	58.648178	16.16817	58.648178,16.16817	58.676817	16.369984	58.676817,16.369984	01:05	01:35	Move to Krokek
OneSAF	ATTACK	USBn1CoAp1	US Army Bn 1 CoA Plt 1	Attack KroC6	58.648178	16.16817	58.648178,16.16817	58.676817	16.369984	58.676817,16.369984	01:40	03:00	Upon arriving in Krokek, Plt 1 attacks KroC6 as main effort, defeats KroC6, then transitions to exploitation operations.
OneSAF	ATTACK	USBn1CoAp2	US Army Bn 1 CoA Plt 2	Attack KroC6	58.648178	16.16817	58.648178,16.16817	58.676817	16.369984	58.676817,16.369984	01:40	03:00	Upon arriving in Krokek, Plt 2 attacks KroC6 as supporting effort, defeats KroC6, then transitions to local security during Plt 1 exploitation operations.
OneSAF	DEFEND	KroC6	Krokek Cell-6	Defend against attack	58.676817	16.369984	58.676817, 16.369984	58.676817	16.369984	58.676817,16.369984	01:40	03:00	Attacked by Co A Plt 1 and Plt 2
JSAF	MOVE	USAQRF	US Army QRF	RTB	58.676817	16.369984	58.676817, 16.369984	58.586727	16.249418	58.586727,16.249418	02:20	02:30	Return to base at Norrköping Airport
OneSAF	MOVE	USBn1CoAp1	US Army Bn 1 CoA Plt 1	Return to AA	58.676817	16.369984	58.676817, 16.369984	58.648178	16.16817	58.648178, 16.16817	03:00	03:30	Return to AA vic Jursla.
OneSAF	OCCUPY	USBn1CoAp2	US Army Bn 1 CoA Plt 2	Occupy and secure Krokek	58.676817	16.369984	58.676817, 16.369984	58.676817	16.369984	58.676817,16.369984	03:00	04:00	Take control of port.
VRF	INIT	1BCT	1BCT (USA IN)	Initial Position	58.586727	16.249418	58.586727, 16.249418	NA	NA	NA, NA	00:00	04:00	In FOB vic Norrköping Airport

Figure B-6: Tasking Plan.

B.8 CREATING C2SIM DOCUMENTS

The GMU C2SIMGUI and OneSAF simulation were used to prepare C2SIM Initialization and order XML files using the data given by the MSEL spreadsheet. These files were distributed to the different participant teams for use in their own applications.

B.9 SYSTEM ARCHITECTURE

Figure B-7 shows the system architecture used for the MiniEx. The different national sites were connected via the internet using a VPN. All the simulations and C2 applications/surrogates required a degree of modification or the development of bespoke C2SIM middleware and a number of lessons have been identified or learned. When appropriate these have been passed to the SISO C2SIM PDG and given as recommendations in Section B.7.2

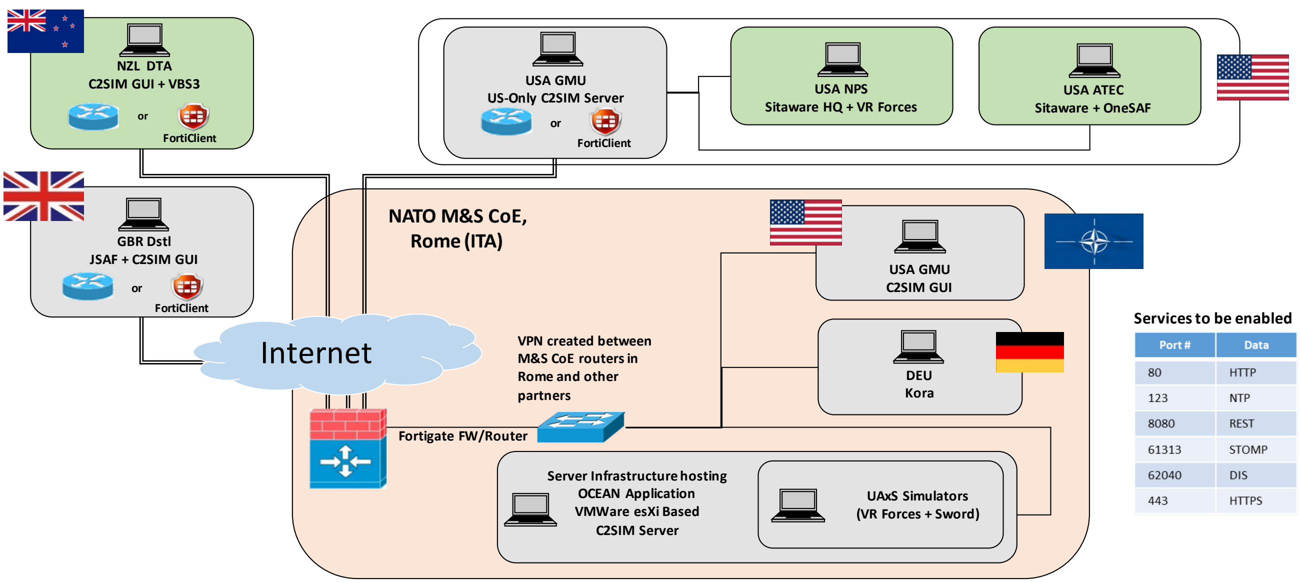

Figure B-7: MiniEx System Architecture.

B.10 SCENARIO INITIALISATION AND EXECUTION

The coordination of scenario initialization was enabled using the GMU WS's initialization capabilities. This allowed C2SIM Initialization documents to be merged (if necessary) and sent to participating applications. How the applications processed the initialization data varied as most of them were legacy applications which had been adapted to process C2SIM messages. Initialization documents contain allocation data giving the initial assignment of each actor, unit, entity, etc. to specific simulations. Of course, these may change dynamically during execution, e.g., through the use of Transfer of Modelling Responsibility (TMR) HLA interactions.

Scenario execution by the simulations was started by the publishing of C2SIM orders via the WS.

B.11 LATE JOINERS

The C2SIM Sandbox Reference Implementation permitted late joiners and re-joiners to query the server for previously published initialization data. This capability was used by at least one participant (NZL) and worked very well.

Annex C – C2SIM AIR OPERATION EXTENSION DEVELOPMENT PROCESS

The C2SIM Air Operation Extension (AOX) is the product/result of a generation process developed on purpose. It is called the "Process for Generation of Interoperability Models". Its purpose is to generalize processes of creating interoperability models whatever the technology (HLA, DIS, MSDL, C-BML…). It is part of a broader process called "System Using Simulation (SUS)" creation process. Both processes have been initially developed for the benefit of the French MOD by AIRBUS. They are both compliant with the DSEEP approach and the GSD approach which recommends refining the analysis and scenario by steps (operational, conceptual and executable)[1].

The "SUS creation process" describes roles and organization, inputs and outputs; it provides support for the people in charge of the management of the process (planning and deliverables). The "SUS creation process" is a nine step process, numbered from E1 (System objectives definition) to E7 (Analysis and evaluation of the results); it is illustrated below. Step 0 (E0 management) and step 8 (E8 capitalization) are transverse and do not appear in the illustration, Figure C-1.

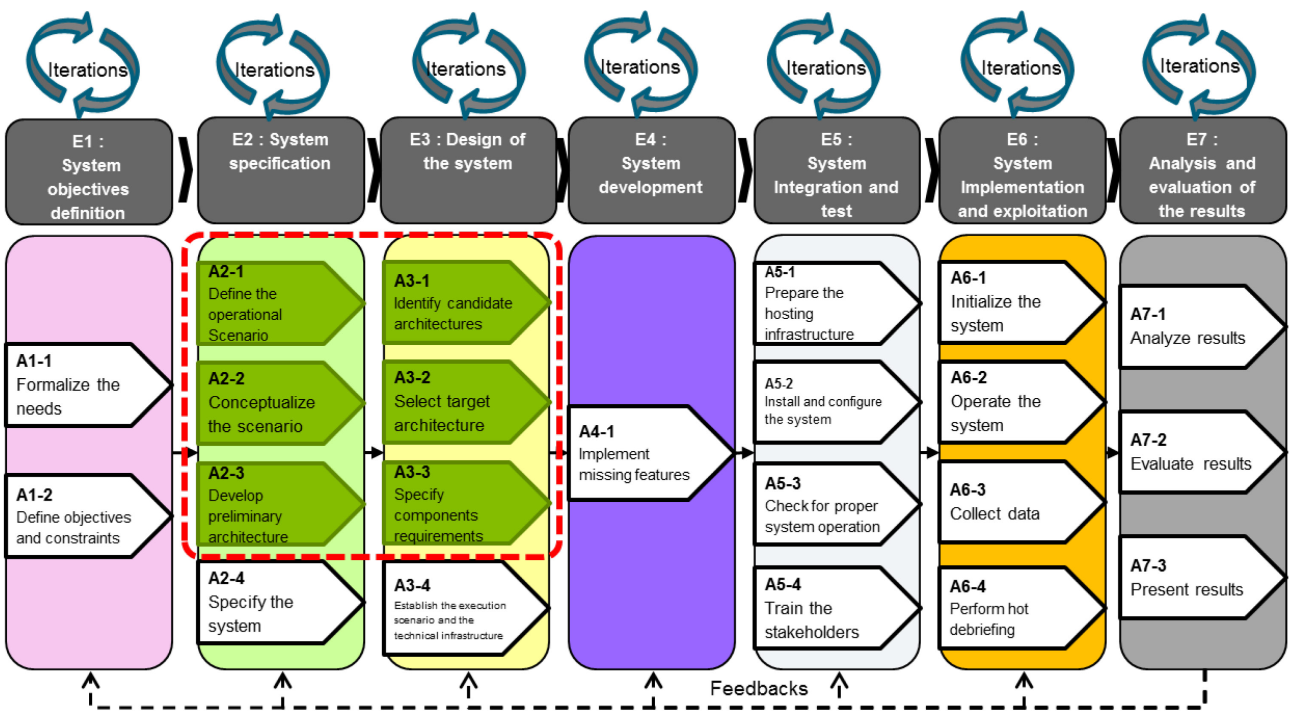

Figure C-1: Process for the Creation of a "System Using Simulation (SUS)".

Development of interoperability models has to be done when developing "Systems Using Simulation". Such development relies on two activities: the development of a model for execution and the development of a model for initialization. The illustrations below, Figure C-2 and Figure C-3, show the two activities. In light blue, the

[1] SISO-GUIDE-006-2018 "Guideline on Scenario Development for Simulation Environments", Section 4.2 describes the scenario development process.

activities being done during the operational scenario definition, in purple the activities being done during the conceptual scenario definition, and in navy blue the activities being done during architecture definition (leading finally when the applications are selected to the execution scenario definition).

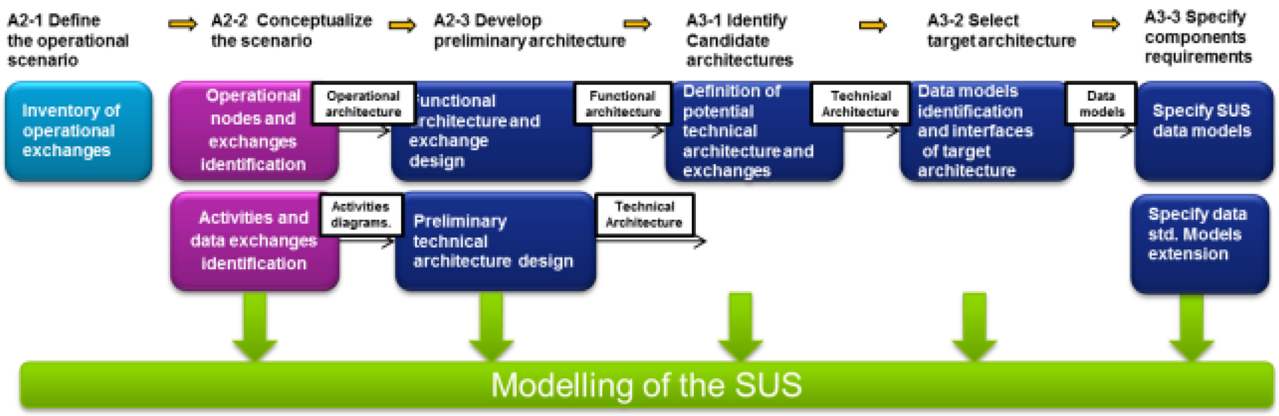

Figure C-2: Process for the Development of Interoperability Models for Execution.

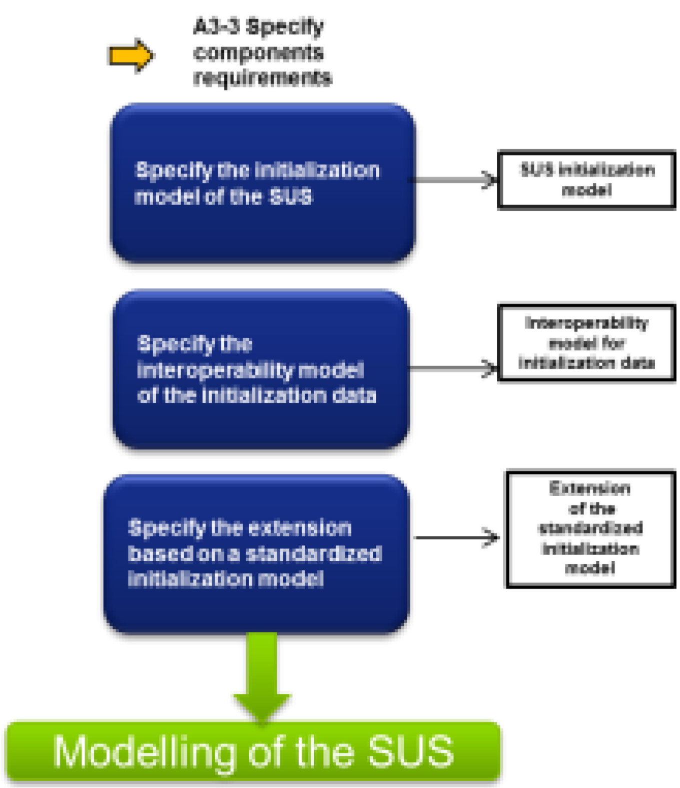

Figure C-3: Process for the Development of Interoperability Models for Initialization.

The C2SIM Air extension has been the result of the process for the development of interoperability models. The stages of the process are listed below:

Model definition for execution:

1.1 Make the inventory of operational data.

1.2 Identify operational nodes and operational exchanges.

1.3 Identify activities and exchanges between activities.

1.4 Define logical architecture and functional exchanges.

1.5 Define physical architecture and interfaces.

1.6 Specify the interoperability model of the data exchanged.

1.7 Specify the extension of a standard interoperability model.

Model definition for initialization:

2.1 Specify the initialization pattern.

2.2 Specify the interoperability model for initialization data.

2.3 Specify the extension of a standard initialization model.

The implementation of this generation process for the generation of a C2SIM extension was effective and an Air operation extension, based on the C2SIM standard, was indeed produced as a result. That being said, the different steps of the process were not equally efficient. The overall process is mostly based on logical steps that were not faulted in this evaluation. Especially since the analysis, which is supposed to lead to the interoperability model, was doubly constrained by the predefinition of a demonstration scenario for the evaluation and by the pre-existence of TDL message formats. Those constraints made it possible to skip some steps. The effectiveness stopped with the technical implementation of the C2SIM extension, namely "producing an OWL ontology" then "generating an XSD schema". Those parts, linked to the C2SIM standard to be, were particularly cumbersome and difficult. The OWL format, chosen by SISO, is complex and not really suitable for interchange between machines: as a consequence, an additional processing step is necessary; OWL ontology must be translated into XSD schemas. The SISO proposes to ensure development (and standardization) of new OWL extensions by itself. This raises questions as technical expertise in the creation of ontology is not enough alone:

- Technical expertise must be supplemented by military/domain expertise (LDT in Air Operations case).
- Technical expertise must be complemented by software engineering expertise to understand the constraints of the interfaces of the components integrated in the Systems Using Simulation (SUS), which is variable depending on the requirements.

C2SIM is breaking new ground and like any standard it embodies compromises. Adopting ontologies as an extension mechanism, as represented in OWL/RDF, was such a compromise. While we have found that the C2SIM extension process is workable, we expect that as the C2SIM community gains experience the process will be improved in flexibility and ease of performance. For now, we find the C2SIM standard to be a useful step forward.

Annex D – STANDARDIZATION PROPOSAL

This standardization proposal format is to be filled in by any interested party to initiate the standardization process through the bottom-up approach. If required the NATO Standardization Office (NSO) can assist the originator to ensure the standardization proposal (SP) addresses the required content and meets formatting requirements. Once completed, please submit to the appropriate tasking authority/delegated tasking authority (TA/DTA). In case of any uncertainty concerning the appropriate TA/DTA, please submit to the NSO.
1. Reference Number: *To be provided by TA/DTA staff / NSO.* — **2. Date*:** *1 September 2019*
3. Originator*: *NATO STO MSG-145 Task Group.*
4. Tasking Authority / Delegated Tasking Authority: *NATO STO Modelling and Simulation group*
5. Subject*: *C2 to Simulation Interoperability (C2Sim).*
6. Standardization Need and Impact on Interoperability*: *Command and Control to Simulation (C2SIM) interoperability standardization efforts have been undertaken for over a decade within the NATO Science and Technology Organization (STO). These activities have identified the military need for nations to not only interoperate and enhance command post forces readiness, but to provide C2SIM support on operations for military planning, mission rehearsal, control of autonomous systems, and to the acquisition life cycle process in nations. Methods for connecting C2 systems and simulations need to be cost-effective and efficient for these applications. Standardizing the exchange of digitized military information for C2SIM interoperation is a solution and will lead to realizing a number of benefits that include:* • *Enhanced realism and overall effectiveness by faster, more consistent information exchange among systems.* • *Decreased cost and risk by reducing manual input (the swivel chair effect), reduced number of supporting personnel and equipment.* • *Reduced preparation and response time with rapid configuration, initialization of systems and validation of scenario.*
7. Urgency*: *1 Jan 2020*
8. Fast Track Procedure: *Not Required*
9. Proposed Standardization Solution*: *A standard based on Simulation Interoperability Standards Organization's Command and Control-Simulation Interoperation (C2SIM) family of products that would enable bi-directional exchange of messages and data between various C2 systems and simulation systems. The family of products are provided in three parts:*

- *C2SIM Core Standard - Type: Standard; Relationship: Has three major aspects: The logical data model that provides the logical definitions of initialization, tasking, and reporting business elements and associations referenced in the syntactic representation standards below; (2) The XML syntax representation for C2SIM initialization messages and procedures for using them; and (3) The XML syntax representation for C2SIM tasking and reporting messages and procedures for using them.*
- *C2SIM Extension for Maneuver Warfare – Type: Standard; Relationship: Example of a C2SIM extension; chosen to cover maneuver warfare C2 information over and above the C2SIM Core, that has seen significant use under MSDL and C-BML standards. An extension to the Core standard, not part of the Core.*
- *Guideline for C2SIM Implementation – Type: Guidance; Relationship: Guideline document for implementing the C2SIM standard.*

10. Related Capabilities: *Combined and Supersedes SISO's Coalition-Battle Management Language (C-BML) and MSDL (Master Scenario Definition Language standards*

11. Level of Standardization: *[If known, please indicate the level of standardization to be achieved through the implementation of the proposed standardization solution.]*

☐ Compatibility ☐ Interchangeability ☐ Commonality

Additional information: *Please indicate any limitation.*

12. Covering Document: *[If known, please indicate the intended covering document for the proposed standardization solution.]*

☒ STANAG ☐ STANREC

13. Non-NATO Standardization Solutions: *Simulation Interoperability Standards Organization – C2Sim Standard Product Development*

14. Working Group: *NATO STO MSG-145 and SISO C2Sim Product Development Group*

15. Custodian: *NATO STO Modelling and Simulation Group*

16. Partner Nations' Involvement: *None*

17. NATO Bodies' Involvement: *M&S COE*

18. Engagement with Other Actors: *Industry and M&S COE*

19. Classification and Release: *NATO UNCLASSIFIED Public Releasable*

20. Languages Required: *[Please indicate the language in which the proposed standardization solution needs to be available.]*

☐ English ☐ French ☐ Both

21. Promulgation Criteria: *If known and applicable (STANAG only), please indicate the promulgation criteria for the proposed standardization solution.*

22. NATO Effective Date: *If known, please indicate the need for a NATO effective date.*

23. Relationship to Existing NATO Documents: *If known, please indicate relationship to existing Allied Standards or other relevant NATO documents.*
24. Military Services Affected: *[If known, please indicate the military services affected by the proposed standardization solution.]* ☒ Joint ☒ Air ☒ Land ☒ Maritime ☐ Other
25. Other Information: *Please report any other information you consider relevant.*
26. Contact Information:
27. Name and Signature*: Name: *[please provide your full name]* Signature: ________________________________ *[please sign]*

* These fields are mandatory.

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14. Abstract

The interoperation between Command and Control (C2) systems and simulation systems is a common theme in the transformation of modern military forces. This is required to support the military enterprise in the execution of business activities and mission threads such as forces readiness, decision support and acquisition. This implies the ability to seamlessly integrate C2 and simulation systems and to provide the means for a meaningful and unambiguous information exchange. This applies to systems of systems functioning toward a common goal at different levels: 1) Within services; 2) Across services; (i.e., joint) and 3) Across Nations in a multi-national or coalition context.

In 2016, the NATO Research and Technology Organization started the three-year Modelling and Simulation Task Group "Operationalization of Standardized C2-Simulation Interoperability" to further the development of the C2 to Simulation interoperability standards developed by SISO with a view to recommending them for adoption by NATO as a STANAG. This final report documents the completed work of this Task Group, designated MSG-145. It includes the continued progress made to demonstrate the utility of C2-Simulation interoperability. This report draws on the knowledge of C2-Simulation experts to merge current standards towards a unified, more manageable and easier to deploy C2SIM interoperability suitable to be recommended for adoption as a NATO standard.

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