GUIDELINES FOR DEVELOPING INTEROPERABLE SIMULATION FOCUSED ON MARITIME OPERATIONS COMBINING AUTONOMOUS SYSTEMS AND TRADITIONAL ASSETS

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ABSTRACT

The main aim of this research is to identify the opportunities and potential for using M&S in addressing the use of autonomous systems to augment maritime capabilities by interacting with traditional assets.. This subject, in this case, is applied on Autonomous systems competing and collaborating with other elements operating over different other domains; the paper address identifies interests, available models and resources as lead to define guidelines and references to create an interoperable simulation framework for training and tactical decision aid.

Keywords: *Autonomous Systems, Interoperability, Modelling and Simulation, Joint Naval Training, Tactical Decision Aid*

INTRODUCTION

The use of simulation is becoming more and more important in many sectors; in particular defense is experiencing revolutionary results in terms of training efficiency and effectiveness through simulation since decades.
The need to combine different models to recreate complex scenarios is a major issue and the possibility to integrate real systems in the simulation is fundamental both for training and for decision making.
Due to these reasons it emerged a need to create simulators as mosaic where the different elements where tiles to be combined based on a conceptual and technological interoperability.
Obviously initially the main problem was about technology and refurbishment of existing simulators to interoperate; therefore these aspects evolved quickly and thanks to Institutional support over passed the classical "stiction" characterizing the introduction of new technological solutions.
These aspects moved up the priority to create models and simulators able to populate libraries for developing complex scenarios; the problem in this case is more deep than just technological, dealing with commercial, IPR, conceptual modelling, security and resolution issues. Therefore it is evident today the potential to create such new interoperable simulation environments by using the models developed in these year as well as the innovative methodologies; all these factors enable the creation of new federations and to properly cover complex scenario by giving access to data, models and resources.
Considering the evolution of the military operations and assets this potential becomes even more strategic, allowing to investigate new procedures, policies, technological solutions over the new mission environments.
Obviously the fast evolving use of autonomous systems is one major driver on this aspect; indeed often it is necessary to develop from the scratches the doctrines and utilization modes, as well as to invent the requirements of the new systems; simulation is probably the only proper solution to address these issues.

Among the critical scenarios the authors propose here the naval operations within maritime extended framework (including multi domains such as underwater, surface, coast, air, space and cyber space); in this case as in other context, the use of autonomous systems is supposed to proceed gradually being integrated with existing platforms and systems.
It is evident the need to develop training and decision support aid based on simulation able to deal with this complex case that is strongly relying on interoperability issues. The author propose here a research carried out in order to evaluate the available resources as well as the potential to further proceed in this direction within a naval scenario involving of autonomous systems competing and collaborating each other and with traditional assets over different other domains.

1. INTEROPERABLE SIMULATION

Indeed the introduction of interoperable simulation further empowered the use of M&S (Modeling and Simulation) even if many actors limited the full achievement of its potential along the last twenty years. Adoption of HLA, as revolution respect DIS concepts within few years along the middle of '90, was really a great achievement; therefore it was not an easy deal for this concept to succeed, and it survived to the industrial inertia and commercial issues mostly based on the US DoD will power and the good will of wise Scientists and technicians from Academia and Industry. The complexity of applying new conceptual design criteria based on distributed object oriented approach resulted not trivial for the developers; this aspects was further reinforced by the necessity to adapt these concepts to legacy systems evolving from obsolete technologies and old architectures. The simulation community applied extensive efforts along these twenty years to support development of skills and background knowledge in the area by many initiatives such as (McLeod / M&S Net Certification program, CMSP, Smackdown Initiative, Simulation Exploratory Experience, Body of Knowledge and HLA Outreach Program) still representing very important achievements and strongholds (McGlynn 1996; McLeod 1999; Amico et al. 2000; Morse 2000; Waite 2001; Ören & Waite 2007; Bruzzone et al.2009; Elfrey 2011).
Therefore the diffusion of HLA and the extensive application of interoperable simulation was even limited by IPR (intellectual proprietary rights) not only on the models and simulators, but mostly on the real systems to be integrated in such interoperable federations (Mevassvik et al. 2001; Huiskamp 2007, Strassburger et al.2008); indeed in most of the case the real systems were expensive industrial products of defense industry. In several country protective actions were also applied to limit the diffusion of the new standards respect the use of previous ones where background knowledge a products were already developed (Boer et al. 2008); so the HLA adoption by NATO as reference guideline in late '90 and its formal recognition as IEEE Standard was promoting it further, therefore its diffusion was not so capillary as it could be expected originally for the above mentioned reasons. Along the years some other approaches for interoperable simulation were proposed, achieving very limited diffusion, often limited to single groups; their reasons for failure included previous issues; but in addition the related results provided often questionable achievements in terms of performance and reliability, plus strong limitations in replicability, and in addition these proposals were missing the effect of DoD actions and were lacking promotion from effective international scientific community (Martínez-Salio et al 2012). So despite we are going to celebrate 20 years of HLA this architecture still the main references for M&S interoperability and guarantees a big potential for further developments by being integrated in modern technologies and innovative approaches (NATO 2009, 2009, 2012). Indeed it is important to outline that HLA is not a technology, but corresponds mostly to an architectural and conceptual approach to distributed interoperable simulation, while its implementation into the RTI (Run Time Infrastructure) is achieving significant improvements over the years through very good commercial products (e.g. Pitch & MÄk) and qualified open source solutions (e.g. Portico).
Due to these reasons it becomes pretty interesting to develop HLA framework for creating new simulation frameworks integrating models and simulators based on innovative technologies. As far as the maritime environment is concerned there are already examples of interoperable simulators used for different purposes including education, training and decision support both on the sea-side (e.g. Longo et al. 2013; Longo et al., 2014) and on the land-side (Bruzzone et al. 2011; Longo, 2010; Longo 2012). Therefore, it is even more evident the possibility to use interoperable simulation to augment the "maritime capabilities" combining autonomous systems and traditional assets. To this end, the main aim of this research is to define guidelines and references models for the creation of such interoperable simulation.

2. SIMULATION TO AUGMENT MARITIME CAPABILITIES

Currently surface ship, underwater vessels and naval air components rely on many sensors including sonar, radar and E/O systems to detect, localize and classify potential threats; even in these day the introduction of autonomous systems (e.g. UAV Unmanned Aerial Vehicles) is leading to the creation of a dynamically evolving sensor network integrated with other assets.
Future scenario are expected to deal with many autonomous systems operating in multiple devices as resources for the opposite actors, so creating a competing and collaborative environment integrated with traditional assets and resources as proposed in figure 1.

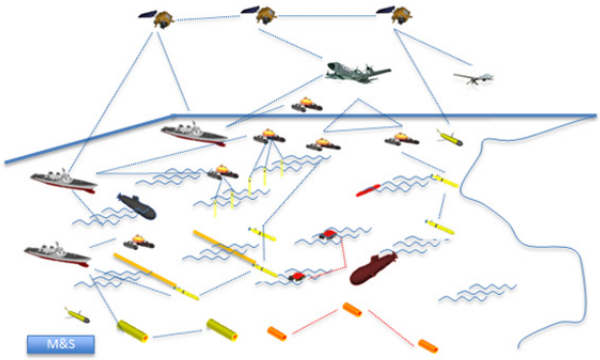

Figure 1 – Example of Possible Future Scenario

Therefore in future we expect that these aspects further evolve by a more intense use of the autonomous systems into operational issues and requiring them to cooperate on complex tasks while operating within different domains.
It is interesting to address the specific aspects related to the ASW (antisubmarine warfare) or MCM (Mine Countermeasures) operations where the complexity of the detection stresses further the need to collaborate over the different domains to augment the capabilities; in this context vessels and sensor infrastructures, helicopters and planes are extensively used and even integrated by innovative AUV (Autonomous Underwater Vehicles). For instance in ASW, the tactical data links provide multiple ships and aircrafts with a means to augment their overall search and classification rates, while multi static approach in active sonar represent a new capability for improvement active search based on interoperable sonar networks including decoupled sources and receivers .
These overall capability improvement result possible by the complementarities of search and prosecution tempos between air and sea surface combatants.

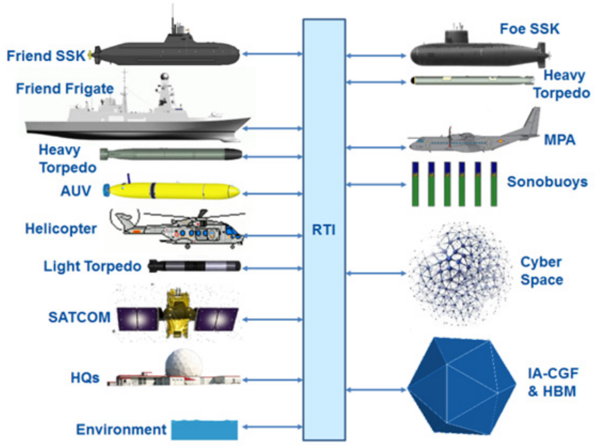

Figure 2 – Example of Federation for Demonstrating the proposed Concepts

The introduction of unmanned maritime systems still affected by heavy limitations in terms of autonomy, range of operation, speed and payload, promote the investigation on how to employ and design them; For instance it becomes important to identify most relevant requirements and most sensitive variables for current and next generation of autonomous systems: e.g. many small light devices or few heavy ones?
It is also very crucial to develop the procedures and policies for using these assets and to combine them within the traditional assets to improve the maritime capabilities.
For instance USVs (Unmanned Surface Vessels) are usually subject to sea limitations while UUVs (Unmanned Underwater Vehicles) are limited in terms of speed, payload, communication capabilities and endurance and Naval UAV still need to improve their capabilities in operating safely from surface vessels. Moreover, all the autonomous systems had to deal with their limits in terms of on-board intelligence and communication throughput.
This last issue suggests the need to develop ad hoc strategies for commanding and controlling them respect just to consider such autonomous assets equivalent to man operated devices; so man-on-the-loop, as high level supervision with task assignment emerge as an additional aspect to be investigate (Magrassi 2013).
Indeed numerous studies and demonstrations on specific systems have been conducted confirming concluded that autonomous systems have some potential to improve effectiveness and efficiency in naval missions (Jans et al. 2006; Been et al. 2007, 2008; Wathelet et al. 2008; Caiti et al. 2011; Strode et al. 2012; Santos et al.2013; Carrera et al. 2014); therefore these analysis were mostly based on mission scenarios or concepts of use strongly related to general assumptions referring to surface ship and/or MPA contributions.
Indeed the goal of this study is to better quantify the benefits of unmanned systems when they are inserted into naval joint operations and interact with traditional assets over multi domains.

3. ELEMENT OF THE FEDERATION

The critical issues to be addressed to face these challenge include several aspect.
A major element is to identify the legacy systems available in the different Nations and Research centers; these include different kind of models and simulators.

***Mission Environments and Behavioral Models*:**
These includes simulators of standard naval missions, search models and algorithms, classification tactics, threat behavioral models for current and future scenarios

Traditional Assets and Platform Models
Models of Surface Vessels and their assets (e.g. helicopter, UAV, AUV), Models of MPAs (Maritime Patrol Aircrafts), Models of Submarines, Models of weapon systems etc.

Sensor Models
Models of different kind of sensors (e.g. radar, EMC, active mono static sonar, multi static sonar, passive sonar, towed arrays, magnetic anomaly detector).

Autonomous System Models
Models of UUV, USV, UAV, AUV and of their capabilities (e.g. communication, payload, movement and autonomy, internal intelligence)

Environmental Models
Models representing the environment and related modifiers on sensor and platform performance (e.g. sea, current, fog, waves, salinity, temperature, thermal layers.)

Command and Control Models
Models about the characteristics and architecture of the C2 and tactical data links (above and under the surface) including rules routing and elaborating data and responsibilities to take decision.

Measure of Merits
Development of models able to quantify over the simulation the performance and the achievement of success over different aspects (e.g. readiness, target accuracy, reliability, cost).

An example of general scheme of the federation to be used for such development is proposed in figure 2 considering a sub set of elements and objects to be federated.

4. ROADMAP FOR DEVELOPMENT

Based on recent survey the proposed topics result interesting for several Nation that is supposed to drive the general roadmap of this activity (Bruzzone 2014).

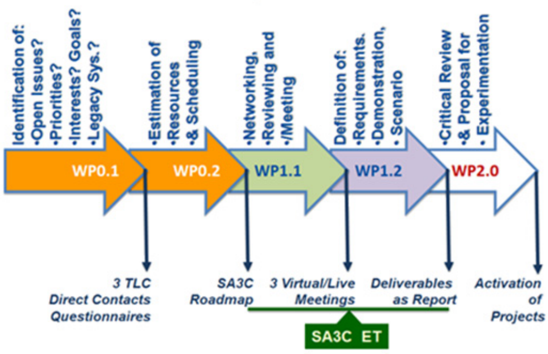

Figure 3 – SA3C High Level Roadmap

Indeed the investigation of multi domain autonomous systems as well as ASW, Port Protection and MCM operations and the related simulation models results very important. The interoperability among the autonomous systems is considered a priority for many stakeholders respect the study of the single system (Massei et al.2013).
The authors identified HLA as the architecture to be used for creating an federation to be used for experimenting the potential of this approach and for providing preliminary results.
Based on preliminary survey different sonar models and engines environmental model, tactical simulators and behavioral models are already available for being integrated in the proposed architecture.
The list of the module under considerations for being federated include scenario generators, C2, IA-CGF (Intelligent Agent Computer Generated Forces), COS Surrogates, AIS Simulators, Maritime Virtual Simulators, Ocean Models, Bottom Reflection and Acoustic Models, Navigation Simulators and a Marine Cyber warfare Simulator.
A major issue to proceed in this research will be to engage operational and technical people as well as scientists over different nations and it is interesting to outline that NATO is already promoting an Exploratory Team dealing with this initiative (NMSG ET-036 SA3C "modeling and Simulation of Autonomous ASW capable vehicles to Augment surface and maritime air Capabilities") and a general roadmap is proposed in figure 3.
Therefore it is evident due to the nature of the case study the sensitivity of most of the data and model, introducing the necessity to properly deal with the security issues during the experimentation; this introduces a major problem for the development of this research; therefore the authors are planning to create a "realistic", but not sensitive, framework based on public domain model could be extensively used to demonstrate the proposed concepts. Indeed the NATO initiative is currently devoted to demonstrate these M&S capabilities, keeping the scenario at lowest possible level of classification and to leave it as an open resource for further investigation by the Nations; indeed this initiative is devoted to create and demonstrate a capability for the future, so there aren't particular constraints for classified simulation in it and this could also reduce impact of these issues on the project coordination and development.
Obviously doctrines, ROE (rules of engagements) and behavioral models as well as asset simulator in this case will be substituted by other models different from real ones and/or meta-models; therefore considering the adoption of a flexible interoperable approach, these elements could be easily substituted with high fidelity federates by the stakeholders for their investigation outside of the proposed experimentation.
In facts it is evident the necessity to develop behavioral elements to be federated into the HLA framework for the proposed demonstration; based on this concepts it becomes evident the necessity to integrate specific models able to deal with the onboard intelligence of the autonomous systems and able to reproduces their situational awareness and collaboration capabilities (Bruzzone et al. 2011b; Bruzzone et al.2013b). These

aspects normally deal with the autonomous system capacity to communicate in real time, or with a certain delay, as part of a dynamic heterogeneous network; this outline the importance to include models of these ICT network and communication aspects reproducing cyberspace (Bruzzone et al.2013a).

Figure 4 – SME and Stakeholder Engagement Plan

In addition to these elements it is important to outline that the C2 systems in this context are often multi level, including single ship, Nation, Coalition, Multi Coalitions operating within the same framework; these aspects require to create models of multiplatform data/contact/track fusion and to simulate multiple concurrent decision processes regulated by the evolving boundary conditions (Bruzzone et al. 2011a).
Despite the research deals with using autonomous systems, it is fundamental to remember that most of the active assets are man operated and their decision making procedure as well as the related human behavioral models (HBM) are crucial element in scenario evolution; this is further evident if this concept is stressed by outlining the importance to model the vessel crew as key element of such weapon systems (Bruzzone 2013c); indeed simulations of human behavior modifiers including rational and emotional elements, workload capabilities, hierarchical autonomy should be consider in the model as critical element further reinforced by conditions of potentially severely limited communications.
Another important aspects include the capability to combine other elements such as cyberwarfare or maritime air E/O, MAD as part of this simulation.
In general the success of this initiative is strongly related with the capability to guarantee SME (Subject Matter Expert) and stakeholder engagement through Verification, Validation and Accreditation (Bruzzone 2002).
The authors are currently promoting this aspect considering the following elements to be part of such interaction:

- Survey on Resources and Capabilities
- Identification of Additional Potential SME/Stakeholders

Contributing on:

- Definition of SA3C Architecture
- Selection of Federates and Models
- Interoperability Architecture
- Scenario Definition

Stakeholders should be part of the Analysis of potential resources and capabilities in order to proper Select/Develop Models, Federates and Federation Architecture
The Stakeholders should contribute to define the Scenario devoted to address main expectations, operational relevance, requirements for available resources and new assets and investigation on alternative solutions.

CONCLUSIONS

Interoperable Simulation for addressing Joint Naval Opertions with specific attention to training and decision support is characterized by different main streams in term of potential:

- Empowerment of legacy systems and internal Activities by enabling Interoperability and Distributed Simulation Capabilities
- Support to Development of New Concepts and Solutions by Virtual Interoperable Testing
- Development of New Capabilities for Strategic Scenario Evaluation by New Simulation Models

Each of these elements represents a great opportunity to enhance the maritime capability through extensive use of interoperable simulation; in the future their synergy could guarantee the possibility to create a new framework for the M&S Community operating over the multiple domains affecting this mission environment. It is evident that these concepts could be easily extended to other scenarios and other problems. In addition the oil and gas off-shore operations represent a very promising opportunity for dual use of these models in surveillance and support to the underwater operations as well as for safety and security procedures.

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