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2024 Annual Review



CHESS



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Preface

Dear M&S Community of Interest,

As we step into another dynamic year, it is my honor to present this edition of the Annual Review, capturing the innovative spirit and collaborative achievements within the Modelling and Simulation domain.

The theme of this year's publication, "*Enabling Multi-domain operations through M&S*" reflects the evolving role of Modelling and Simulation as a cornerstone of multi-domain operations and as a catalyst for creative problem-solving in an ever-changing environment.

Within these pages, you will discover a wealth of insights from our community—ranging from groundbreaking research to practical applications—highlighting the ingenuity and dedication of those shaping the future of M&S. This edition also includes select contributions from the 2024 CA²X² Forum, showcasing the depth of expertise and thought leadership shared during this landmark event.

I wish to express my sincere appreciation to all authors, researchers, and practitioners who have contributed to this publication. Your efforts and commitment continue to drive our shared mission forward, fostering innovation and excellence.

Thank you for your engagement and support of the NATO M&S Centre of Excellence. May this Annual Review serve as a valuable resource and source of inspiration as we navigate the challenges and opportunities ahead.

Happy reading!

Best regards,
Col. Francesco PACILLO
NATO M&S CoE Director

Part 1:
NATO M&S CoE Annual Review

Development Of The "Cyberspace Hybrid Warfare For Educational Strategic Scenarios" (CHESS) At NATO MS COE In 2024

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Abstract

The "Cyberspace Hybrid Warfare for Educational Strategic Scenarios" (CHESS) wargame, developed at the NATO Modelling and Simulation Centre of Excellence (NATO MS COE) in 2024, represents a unique and forward-looking approach to Cyber warfare training and education for a strategic level audience. It exemplifies a groundbreaking approach to Cyber warfare education. Utilizing the PMESII (Political, Military, Economic, Social, Information, and Infrastructure) framework, CHESS enhances training by providing realistic and dynamic scenarios for strategic decision-making. This paper discusses the program's development, its incorporation of PMESII methodologies, and its presentation at key NATO events, including the NATO Centres of Excellence Marketplace, WIN24, and the CA2X2 Forum.

1. Introduction

Modern warfare challenges require comprehensive training that combines cyberspace operations with an understanding of multi-domain interdependencies. The evolving nature of conflict has placed cyberspace and hybrid threats at the forefront of NATO's operational focus. The Alliance has recognized the urgent need for an adaptable and comprehensive educational tool to train leaders and stakeholders in addressing these challenges effectively. Thus, CHESS was conceptualized as a multidisciplinary program integrating strategic thinking, within a Cyber warfare framework. Central to its methodology is the PMESII framework, enabling scenarios that reflect the complexities of real-world environments.

CHESS is a serious strategic-level tabletop wargame that pushes participants to manage complex cyber threats within multi-domain hybrid scenarios. It immerses

players in a realistic pre-war environment, emphasizing the integration of PMESII (Political, Military, Economic, Social, Information and Infrastructure) variables into strategic decision-making within the Cyber Domain.

Combining advanced simulations, real-world scenarios, and innovative pedagogical strategies, CHESS has been designed to enhance NATO's capabilities in addressing complex challenges in the Cyberspace Domain. This paper outlines the development process, highlights key features of the CHESS framework, and discusses its unveiling at notable events, including the Wargaming Initiative for NATO 2024 (WIN24) – Hamburg (Germany), where it garnered significant attention. The paper concludes by emphasizing CHESS's strategic relevance and its potential impact on NATO's readiness and resilience in Cyber warfare.

Developed by the NATO Modelling and Simulation Centre of Excellence, "**CHESS**" is a unique platform for hands-on learning in:

Cyber Conflict Management and engagement with Cyber Threats: Participants face evolving hybrid scenarios that require real-time responses and strategy adaptations. Players engage in scenarios featuring hybrid warfare and cyber crisis response.

Strategic Decision-Making: Strengthen critical thinking and strategy development under pressure, while the risk of war (invoking Article 4/5) increases and decreases throughout the game, compromising the stability of the countries being played.

Cross-Domain Integration: Apply NATO doctrines to navigate the convergence of cyber and conventional warfare.

Incorporation of PMESII Variables: Each scenario challenges players to analyze how political dynamics, economic factors, social contexts, information flows and infrastructure conditions are influenced by the Cyberspace Operations outcomes.

The introduction of CHESS in 2024 leveraged NATO MS COE's expertise in modeling and simulation to create a robust and immersive learning environment. This initiative aligns with NATO's broader objectives of innovation, adaptability, and preparedness for 21st-century challenges.

2. Ideal Participants

“CHESS” is crafted for:

Leadership training: Senior commanders, decision-makers and policy makers, and cyber strategists.

Cybersecurity and Defense Experts: Professionals in the military and defense sectors.

Academic & Research Institutions: Scholars and researchers specializing in cyber defense, wargaming, and hybrid warfare.

3. Development Process

The CHESS framework was developed over the course of 2024 through a structured process that involved:

Needs Assessment: Identifying gaps in current training methodologies for hybrid warfare and cyberspace operations.

Design and Simulation: Creating realistic scenarios that incorporate elements of cyber threats, misinformation campaigns, and multi-domain operations.

Collaborative Input: Engaging experts from NATO member states, academia, and industry partners to refine the content and delivery mechanisms.

Testing and Feedback: Piloting the program with select groups and incorporating feedback to enhance usability and impact.

4. Incorporating PMESII in CHESS

Generating Valid and Realistic PMESII Start Values for Serious Wargames and Simulators provides a holistic approach to assessing and simulating a nation's stability and operational conditions. CHESS leverages this framework by:

Scenario Construction: Using open-source data to create dynamic, interconnected PMESII dimensions.

Cross-Impact Weighting: Refining the interplay between PMESII elements for greater scenario fidelity.

Adaptability: Enabling customization for diverse mission profiles and regional contexts.

By integrating LTC. Weissenberger's cross-impact weighting methodology, CHESS ensures scenarios remain data-driven, objective, and highly adaptable.

5. Key Features and Benefits

The success of CHESS resides in several innovative elements, which it integrates to achieve its objectives:

PMESII Integration: Multi-domain interdependencies that mirror real-world complexities, highlighting the cross-impact weighting, refining the interplay between PMESII elements for greater scenario fidelity.

High-Fidelity Scenarios: Real-world inspired scenarios featuring realistic cyber challenges in a hybrid warfare situation that evolve based on user actions, testing decision-making and adaptability. Gameplay enhanced by updated open-source data relevant to the countries being played.

Strategic Depth: Designed for senior leadership to foster expertise in cyberspace operations strategy.

Collaborative Learning Environment: Network with experts from political, military (national and international staff) and other strategic domains for a unique learning experience.

6. Showcasing CHESS

CHESS was presented at several key NATO venues and international events in 2024, including:

NATO DEFENCE COLLEGE, Rome (Italy): Senior Course volunteer attendees played the game and provided significant contributions to the consistent development of this game at the strategic level:

NATO Centers of Excellence Marketplace, 24–27 May, Brussels (Belgium): CHESS debuted as part of the NATO COE Marketplace, emphasizing its role in preparing NATO for cyber warfare challenges. Attendees explored the platform's PMESII-driven scenarios during live demonstrations.

Wargaming Initiative for NATO 2024 (WIN24), 2–4 September, Hamburg (Germany): Featured at the WIN24, marking a milestone in NATO's wargaming and Cyberspace Operations advancement. Live game play

showcased the game's capabilities, attracting interest from military leaders and defense analysts. Participants engaged in playing the wargame that highlighted the program's using the PMESII framework to influence the cyber domain and vice versa.

CA2X2 Forum 2024, 24–26 September, Rome (Italy): The CA2X2 Forum featured CHES in its agenda. Successfully presented during the forum, engaging experts and leaders from across the M&S and Wargaming community. Experts discussed how PMESII scenarios foster deeper strategic insights and preparedness within the cyber domain.



Figure 1. Live demonstration of the first prototype of CHES with NATO Defence College representatives, Rome (Italy).



Figure 3. Live game sessions at the Wargaming Initiative for NATO – 2024, Hamburg (Germany).



Figure 4. LTC. DEU Army Bernd WEISSENBERGER Presenting the PMESII framework use for CHES development (CA2X2 Forum).

7. Strategic Impact

The development and deployment of CHES underscore NATO's commitment to leveraging innovation for strategic advantage. By using the PMESII framework,

CHESS prepares decision-makers to navigate complex operational environments. Its adaptability and realism enhance NATO's readiness in countering hybrid threats across multiple domains.

CHESS is more than just a training tool. It is a strategic enabler for NATO's collective defense. By equipping leaders and practitioners with the skills and knowledge to navigate cyber threats, CHESS enhances NATO's strategic readiness and resilience. Its interdisciplinary approach ensures that participants gain a comprehensive understanding of cyber warfare dynamics, fostering collaboration across domains and nations.

8. Conclusion

CHESS marks a significant milestone in strategic cyber warfare education, offering NATO a realistic platform for training and strategy development. By incorporating validated PMESII methodologies and open-source intelligence, it sets a new standard for simulation-based training. The program's successful reception at the NATO Centers of Excellence Marketplace, WIN24, and CA2X2 Forum demonstrate their relevance and potential to shape the future of NATO's educational and operational initiatives.

CHESS is also fundamental to lead to an upcoming digital version of the game and a future simulator development of the same game, allowing the possibility to extend the use of CHESS from remote and integrate it within a strategic multidomain simulated scenario. As NATO continues to adapt to an ever-changing security landscape, CHESS serves as a testament to the organization's commitment to innovation and excellence. The program's success at various events underscores its value as a critical tool for the Alliance's future preparedness and training.

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ELMO (Electromagnetic Layer for Multi-Domain Operations) sharing of Information with Computer Generated Forces tools

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Abstract

The electromagnetic environment is essential for understanding and conducting military multi-domain operations. Therefore, the comprehension and management of this physical dimension is crucial.

The NATO Modelling & Simulation Centre of Excellence (M&S CoE) developed a project called "ELMO" (Electromagnetic Layer for Multi-domain Operations), which aims to create a synthetic environment for the virtualization of the so-called Electromagnetic Spectrum Operations (EMSO). The ELMO's follow-up consists of a technical evolution providing additional features beyond the ones already developed. The system provides jamming and radar coverage areas calculation and visualization capabilities. ELMO allows also to generate georeferenced files shareable with other M&S systems, including Computer Generated Forces (CGF) tools. Files sharing is carried out with the "Wargaming Interactive Scenario Digital Overlay Model" (WISDOM), which allows data exchange through HLA1516e. Connection tests have been conducted with VBS4 (also with direct plugin), JCATS and MASA SWORD simulators.

This paper describes ELMO Project's achievements, providing evidence of ELMO capability of its use in all M&S pillars: Education and Training (Exercise), Support to Operations - Execution (Decision Support), Concept Development & Experimentation (CD&E) – Capability Development, Mission Rehearsal - Planning (Course of Action Analysis) and Procurement.

1. ELMO Project Quick Overview

The electromagnetic environment is an essential element for the understanding and conduct of future military operations. Its transversal characteristic permeates the operational scenario in a multi-domain

perspective and, therefore, the comprehension and management of this physical dimension is crucial.

The NATO Modelling & Simulation Centre of Excellence (M&S COE) has developed an architecture called "ELMO" (Electromagnetic Layer for Multi-domain Operations), to create a synthetic environment for the virtualization of the so-called Electromagnetic Spectrum Operations (EMSO). In this context, M&S expresses flexible characteristics for the implementation of complex electromagnetic multi-domain scenarios, able to make visible in the scenario what is not visible or detectable in a real-world environment. This feature would simplify the understanding of the main electromagnetic spectrum parameters and enhance the operational and informative characteristics, which the electronic assets provide within the Electronic Warfare context.

The EM layer was built using the Software Tool Kit (STK), developed by the AGI Company, and MATLAB, developed by the Mathworks Company. The integration of the two tools was exploited to generate ad-hoc synthetic military components such as Jammers and Radar Warning receivers.

A specific scenario was then built in order to simulate a military EM environment, where the STK synthetic assets, such as satellites, radars and communication systems, interact with the military components developed in MATLAB. The EM layer generated by the MATLAB-STK integration successfully provides a comprehensive visualization over time of the entire electromagnetic spectrum on the battlefield. Figure 1 describes an example of this visualization, where the Electromagnetic field area is clearly visible with color code representation related to its power density. In this case, power is focused on the enemy radar to make the jamming more efficient.

The tests performed in a demo scenario with interacting objects virtually operating in a comprehensive EM environment proved the capability of ELMO to develop a complex framework suitable, not only for Commanders' decision-making support, but also for capability Development, Experimentation, Training, Procurement and any possible application area of M&S.

These tests were organized in order to include any possible platform in a synthetic multi-domain environment and simulate several Electromagnetic Spectrum Activities to include but not limited to:

electronic defense, electronic attack and EM spectrum measurements. Considering their role, it is important to describe clearly some of the components included, which have been used to further develop the system as described in this paper.

The first system was a communication jammer installed on a moving blue forces land platform able to inhibit 2G and 3G communication in active mode using the library taken from the intelligence to protect a high value target against radio controlled IED. This protection system provided a “safety bubble” which depends on many elements, including the technical characteristics of the jammer and the communication systems, taking into consideration the different possible distances of the antennas, the terrain, the buildings, the weather conditions, etc..

The scenario included also a blue forces UAV monitoring the EM spectrum with an ESM device as payload. Using the frequencies provided by the UAV, the jammer was able to efficiently inhibit the communication frequencies also in reactive mode increasing the probability of success of the jamming activity. This additional capability was able to hinder the terrorist to activate the RC-IED at the right distance to damage the moving land platform.

Furthermore, during the tests, a blue forces radar was simulated to guide missiles launched from a land battery, controlled by the red forces. The radar was jammed from a jammer installed on a second blue forces UAV directing the energy to the radar position through a synthetic defined antenna.

Moreover, a Position, Navigation and Timing (PNT) Jammer was used by the red forces to inhibit the GPS and GALILEO PNT devices over a wide perimeter within the Area of Operations.

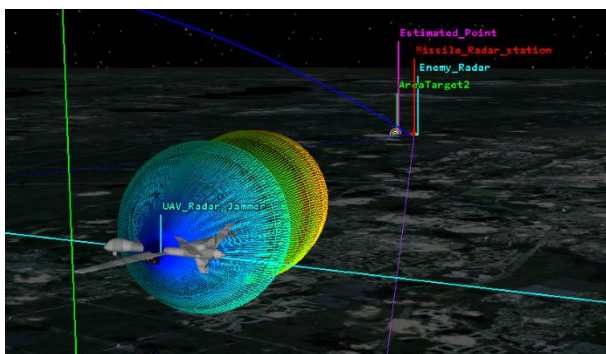


Figure 1: ELMO virtual environment visualization.

2. Wisdom Quick Overview and its Role Within the Experimentation

Over the years the M&S COE has developed the Wargame Interactive Scenario Digital Overlay Model (WISDOM), a software tool for the configuration of geographical scenarios. This platform is particularly suitable to carry out Wargaming activities and is aimed at those who need to perform education & training activities, experimentation, AAR or preparation for real missions, both in the military and civilian context. The platform is designed to reuse and tailor available scenarios or to develop new scenarios from the tactical, operational or strategic level. Thanks to its state-of-the-art architecture, wargamers around the world can access WISDOM directly from their location as it is built to support distributed execution. WISDOM is not a simulator but a Wargaming platform, therefore an upgrade was developed to increase its flexibility and the possibility of being integrated with M&S systems. A specific HLA plugin has been implemented to share entities with M&S platforms and the tool is now able to receive time information from other simulators and visualize entities as well as create and share additional ones.

Thanks to the mentioned upgrade, the entities created by ELMO are now shared on WISDOM receiving the timing from a simulation tool (e.g. MASA SWORD) and updated with the chosen time step.

3. Optimization of the tool usage through friendly Graphical User Interface (GUI)

To make ELMO more user friendly, a set of Graphical User Interfaces using C# has been developed. The GUI allows the simulations to run without using STK and is able, through a simple drop-down menu, to select the specific EMSO action and the main associated parameters.

In detail:

- GUI #1 is devoted to applying the sub-session of the scenario that allows the radar position's calculation thanks to the use of the Doppler shift measured from several (four in our case) LEO satellites. Through the GUI it is possible to select receivers and transmitters involved and the main numerical value.
- GUI #2 uses ELMO to test the jammer UAV capability to effectively inhibit the missile battery radar. In this specific case, it's possible to select the desired objects involved in the test (UAV, Radar),

their payload as well as the numerical value, such as the jammer power. Some data can be taken from previous calculations (e.g. radar position estimate).

- GUI #3 is used for GNSS PNT Jammer calculation. Thanks to this feature, it is possible to understand the jammer's effects on each platform depending on their distance and position. The GUI is able to calculate effects on both GALILEO and GPS constellations.
- GUI #4 purpose is to provide ELMO capability to identify enemy system position by a camera mounted on the UAV. In this specific test, using a preloaded database, the GUI entered data allows the UAV camera to start a true visual search of the GNSS Jammer. If the jammer is recognized, the position information is sent to the blue forces ship for the missiles strike (Kinetic action).
- The following activity run by GUI #5 is the Electromagnetic Spectrum Monitoring (ESM), which determines the setup of the objects, the data related to the detection system and the possible source of EM activities in the frequency range of interest.

Starting from these ones, other GUI have been developed not only to easily run a software package set for a specific purpose, but also to automatically perform complex calculation to determine new and interesting information, as described in detail in the following paragraphs.

station) involved providing also a model for the mobile phone used by the terrorists. The behavioral model is able to calculate in each point if the jamming system is able or not, to inhibit communication, using the jamming over signal ratio. The question now is: Is the "safety bubble" big enough to protect a vehicle along a specific path? To answer this question, a specific GUI has been developed, starting from the one described in the previous paragraph. The GUI is able to calculate with a specified granularity and radius the coverage, in terms of jamming over signal ratio, around the platform where the jammer is installed. For this specific purpose, it is required to set the information described in the following table:

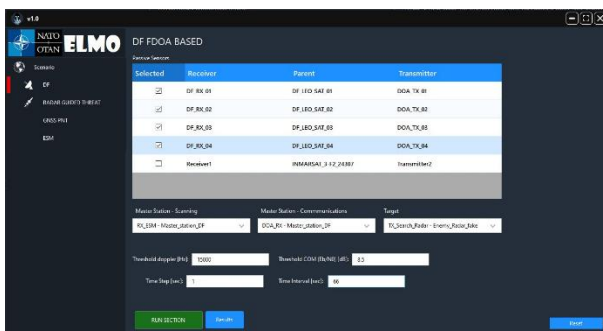


Figure 2: ELMO basic GUI.

4. Generation of communications jamming area and export to other tools

One of the main applications developed in the scenario is the capability of replicating the behavior of a communication jammer, both in active and reactive mode. As described in ref. 1, the jammer developed and tested is able to inhibit the frequencies of 2G and 3G communication systems. The tool has a high-fidelity reproduction capability, not only of the jammer installed in the vehicle, but also of all the BTS (base transceiver

Information to be set	Default information	Description
Target Receiver	RX_GSM_31 – MS	This is the device to be jammed, e.g. the RC-IED. Taken from a list.
Target Transmitter	GSM_931_0 GSM_931_4 GSM_931_8 UMTS_2127_5 UMTS_2132_5 UMTS_2137_5	These transmitters can send and receive information from the device to be jammed. The jamming is also against these devices.
Jammer	Hybrid_Jammer_2g – Jammer_Vehicle	This is the jammer installed in the platform
Jammer Frequency [Mhz]	950	
Jammer Power [dBW]	50	
Number of Layers	4	These are the number of circular areas that define the granularity to build the safety bubble
First Layer Elements n°	2	This is the number of section of the first circular area, the numbers, then, double layer after layer.
Threshold (J/S [dB])	20.0	Determine the effectiveness of the jamming (“probability of security”).
Jamming Range	40	Maximum distance to take into account for the safety bubble (meters).
Start Time	27 Feb 2023 11:16:32.945	Determine when (and so where) to start the safety bubble calculation.
Stop Time	27 Feb 2023 11:17:50.952	Determine when (and so where) to stop the safety bubble calculation.
Analysis Time Step	2	Determine the time update of the calculation (seconds).

Table 1: Info used to elaborate the safety bubble.

In order to create the safety bubble, the user selects the desired RC-IED receiver from the GUI and the tool automatically generates a series of receivers all around the vehicle within circles and cloves. The single receiver area changes its color depending on the BTS signal reception. The area becomes green if the jammer signal is over the threshold or turns red otherwise.

The safety bubble visual representation is therefore able to evolve over time providing a useful capability when planning a vehicle movement in a contested area, training personnel for EMSO activities, testing new jamming systems during its development or procurement phase.

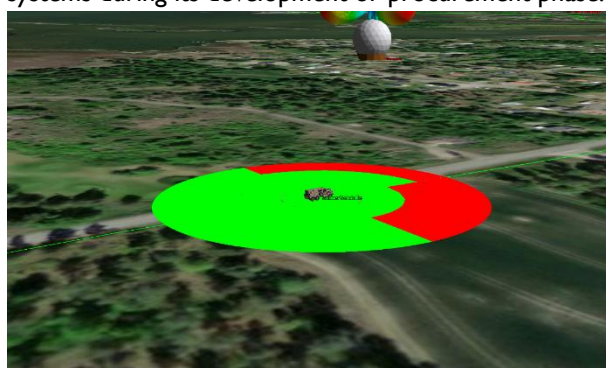


Figure 3: example of communication jamming area visualization.

After reaching the goal of visualizing EW effects on STK, the developers found a way of sharing data with other Wargaming and M&S tools. The same GUI software package described in the previous paragraph was used to generate data in shapefile format so that georeferenced information, evolving over time with the same time-step used for the calculus and visualization, could be shared through the WISDOM platform used as a bridge. The files were then visualized and updated within WISDOM. Interoperability and effectiveness of this new capability have been tested during the NATO CWIX 2024 (Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise) using the Computer-Generated Force M&S tool SWORD (MASA Company) providing the terrain and the scenario of any desired Area of Operation while WISDOM was sharing the jamming area with SWORD using HLA.

The jammer and its safety bubble were locked on the position of a moving vehicle created in STK and evolving over time. Using the HLA plugin in WISDOM, it was then possible to obtain this post processing synchronization and reproduce the vehicle path and its jamming area in SWORD.

The synchronization was achieved by disabling the randomness in any SWORD decision process that could affect the jamming area position & timing in order to be consistent with its associated vehicle. Moreover, the jamming areas shapes complexity was reduced by decreasing the number of polygons shared with WISDOM through HLA. Both visualizations are shown in the following picture.



Figure 4: Jamming area visualization within WISDOM (left – green area) and SWORD (right – red area).

5. Generation of PNT jamming area and export to other tools

Another important application developed in the scenario is the capability to replicate the behavior of a PNT jammer that can inhibit the Position, Navigation and Timing of all platforms around the static antenna in the area of operations. The ploy to solve the issue is the same described for the jammer safety bubble: verify with a specified granularity over the area of operations, all positions where the jamming is above the satellite's signals, with a specified threshold. Also in this case, using the same process, the GUI has been built to determine the GNSS jammer coverage. In other words, in the area where the jamming signal is higher than the GPS and GALILEO ones, the devices based on these technologies become useless. The shapefile built through this process can be shared with WISDOM and with other M&S tools, depending on the jamming area protocol applied (e.g. NATO HLA NETN FOM High Level Architecture NATO Education and Training Network Federation

Object Model). The visualization of this area in WISDOM, STK and SWORD are shown in the following picture. Presently, the process is static but can evolve towards dynamic calculation and visualization applying the same procedure of the communication jamming area described in the previous paragraph.

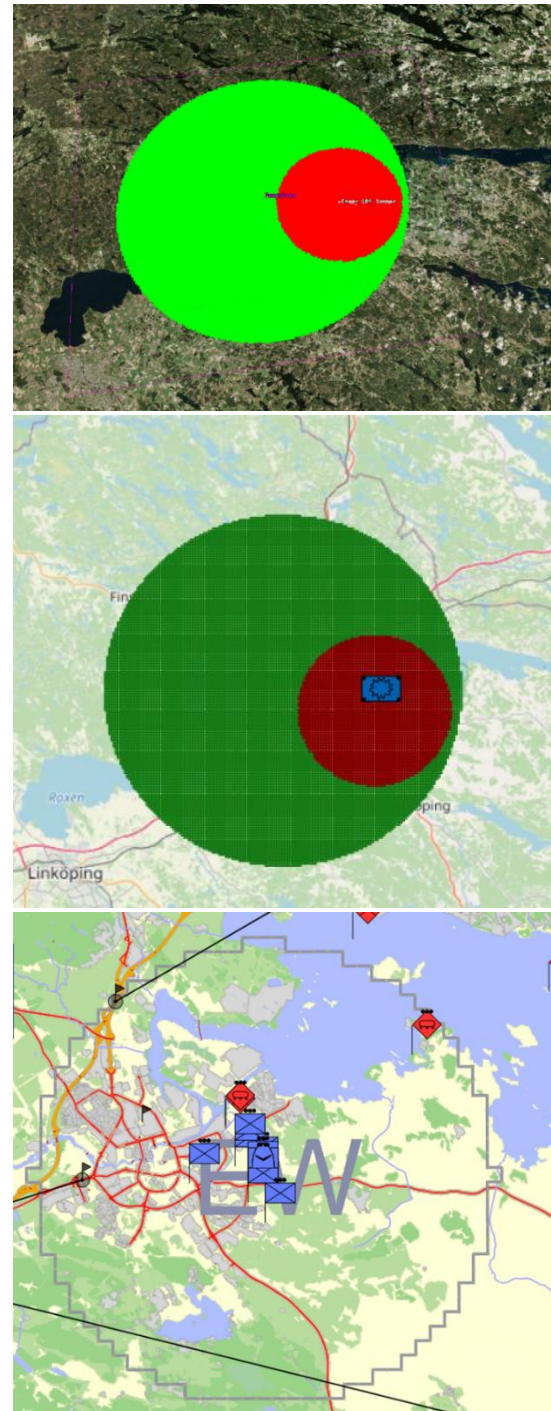


Figure 5: PNT Jamming coverage as visualized by STK (up), WISDOM (down left) and SWORD (down right).

6. Generation of radar Range areas and export to other tools

A different type of application developed in the scenario is the capability to replicate the behavior of a Radar in terms of technical performance. In detail, the technical idea is to verify, with a specific granularity over the area of operations, all positions where the radar can detect a possible target, with a specified probability threshold, that is determined for a specific radar cross section of the target. Also in this case, the GUI has been built to determine where the radar is able to identify the target (Radar Coverage) and consequently perform its mission. The shapefile built through this process can be shared with WISDOM and with other M&S tools, depending on the radar range area protocol availability (e.g. NATO HLA NETN FOM). The visualization of this area in WISDOM and STK is shown in the following picture. Presently, the process is static but can evolve towards dynamic calculation and visualization applying the same procedure of communication jamming area previously described.

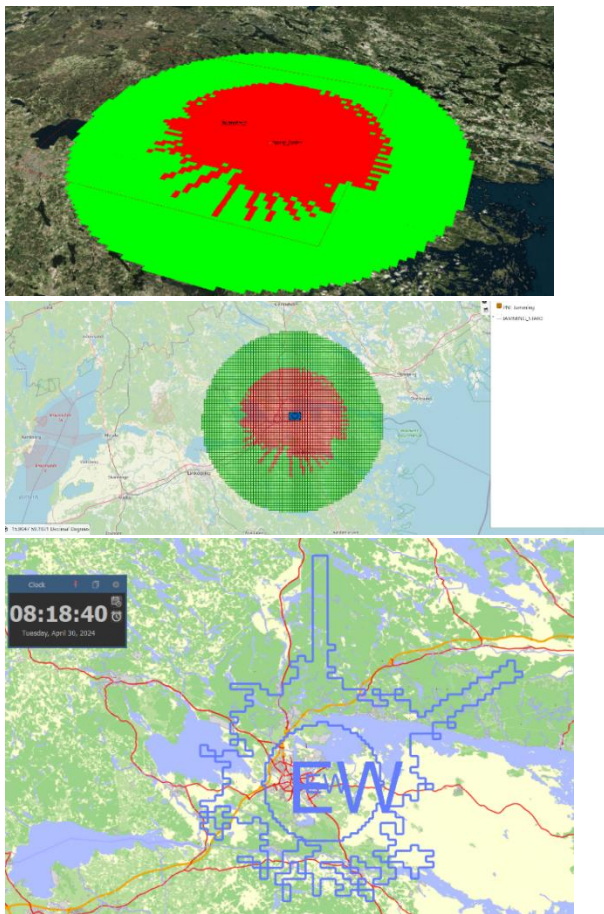


Figure 6: Radar coverage as visualized by STK (up left), WISDOM (up right) and SWORD (down).

7. Data export from WISDOM to SWORD and VBS4 using HLA.

Simulators are generally used for testing activities and not for this kind of application, meaning that only “handicraft” methods have been developed over time. The solution identified in this study for the EMSO objects data export from WISDOM to CGF simulator was performed using the most appropriate NETN FOM to standardize the process for HLA users.

SWORD for instance can generate jamming areas and share them through HLA, only if the other tool uses the same Object to identify them, namely the “EnvironmentObject.ArealObject.OtherArealObject”.

This is a general-purpose object which was used to define these specific activities, but it works only if the other simulators identify the Object in the same way and have the capability to visualize and handle jamming areas. As a matter of fact, The COMMS NETN FOM module does not include any of the areas developed in this project, so there is a clear need to extend the developed modules towards EMSO activities which, independently from this project, will be predominant in future warfare.

8. Additional interoperability test

In order to develop the system to be applied in other areas, other protocols will be considered in the future. As a matter of fact, an impressive number of possible applications could rise if the system is able to send information beyond the word of M&S tools. The multi-domain nature of the project easily opens its applications towards any kind of Command-and-Control Systems. NATO has developed several protocol standards to drive the sharing of information among these kinds of tools, named Tactical Data Links (TDL). TDLs easily allow to share information using the same protocols. The most promising seem to be the ones used with Link 16 and Link 11 communication protocols.

9. Conclusions And Perspectives

The ELMO project continues evolving and increasing its numerous potentials uses and applications. The best way to accelerate this process can be accomplished by increasing the calculation optimization providing guidance to the STK software and by making it more user friendly through a specific GUI.

The system is presently able to calculate, with high fidelity the following functionalities:

- jamming areas (safety bubble) around platforms, as a function of jammer characteristic and surrounding electromagnetic and physical environment.

- radar coverage, as a function on radar cross section of the target, radar characteristics and surrounding electromagnetic and physical environment.
- The functionality of PNT systems when a GPS and GALILEO jamming system is active in the Area of Operations, as a function of jamming system characteristics and surrounding electromagnetic and physical environment.

Functionalities outputs are properly arranged in terms of data selection and formatting, following, when feasible, the most appropriate NATO standardization agreement and have been shared with other tools to test system interoperability.

The plan for the way-ahead of the project consists of the implementation of specific software packages to extend as much as possible the integration of technical information within all available systems, including C2 starting with the ones using LINK16. Moreover, Hardware in the Loop (HIL) software packages will be employed to extend the possible use of the system for equipment training and testing/development activities. Another important outcome of this experimental activity is the clear need for the M&S community to develop dedicated EMSO standard within the already existing NATO Education and Training Network standards. This specific target will be addressed through the NATO MSG-223 that is responsible for the future evolution of HLA151E6 standard and the related NATO NETN FOM and SISO developers.

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MAIDEN (Military Artificial Intelligence for Decision making and Experimentation within NATO)

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Abstract

Artificial intelligence (AI) is an emerging technology that has been progressively developing in the recent period. In particular, the machine learning (ML) is finding substantial use within digitized contexts, favouring the development of innovative concepts and solutions in the IT sector. In the context of emerging technologies exploration, the integration of AI with Modelling & Simulation (M&S), including any possible technical solution such as Deep Learning and Supervised Learning, assumes a fundamental technical and operational value for the benefit of military operations and concept/capability development, with the aim of supporting the decision-making process.

In this context, it should be noted that the fundamental peculiarity inherent in the main AI/ML applications lies in the deductive programming mode, in contrast to conditional algorithms, which are structured on an inductive logic. The deductive logic represents the foundation of the initial concept, or rather, an adequate integration of the AI/ML with M&S.

In particular, the proposed integration provides architecture based on the bi-directional connection between a neural network and M&S tools, in order to extend the peculiarities and results provided by a synthetic environment with algorithms based on deductive logic. The technological coherence of the proposed integration is essentially based on the main characteristics of the computational processes put in place by a constructive/virtual simulator, which refer to stochastic results.

The result would be an integrated system able to “predict” the best behavior (Course of Action) in a specific situation, based on its experience in similar situations. This integrated system would be applied for decision-making support within training activities or, ideally, for real operations, at least in the planning phase.

This paper describes in detail the conceptual project, named MAIDEN (Military Artificial Intelligence for Decision making and Experimentation within NATO), to integrate M&S tools with AI.

1. Keywords

Artificial Intelligence, M&S, Integration, Decision-Making.

2. Introduction

The fundamental peculiarity of this project is the willingness to exploit the deductive programming mode, which is embedded within the main AI/ML applications, in contrast to conditional algorithms, which are structured on an inductive logic and are normally used within tradition coding activities. The deductive logic represents the foundation of the initial concept because it enables to really mimic the behaviour of the human minds, thus providing real support to decision making process, which is based on the previous experience filtered by logic. Programmers tended to define Computers as super-speed idiots. The technological evolution now enables to think about a sort of revolution built a super-speed smart stuff, even if super-specialized.

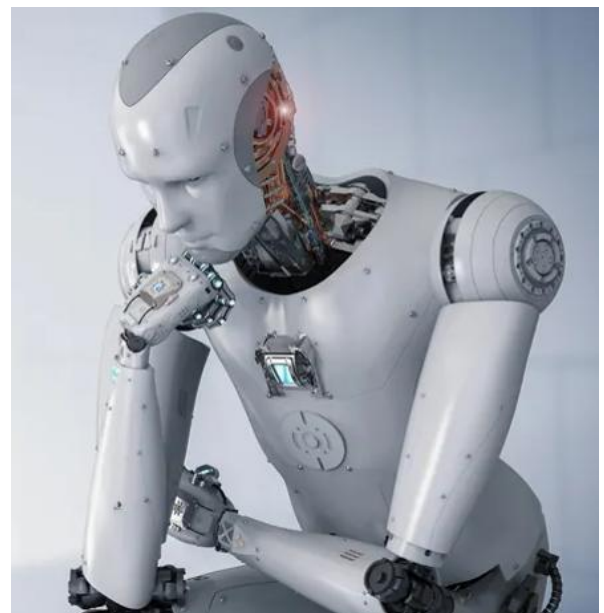


Figure 1: Artificial Intelligence allows computers to mimic human beings' deductive logic.

The basic concept is to design and implement an architecture, including all the hardware and software components necessary to implement the network and to allow its use, through appropriate user interfaces. The architecture must be provided with suitable connection bridges capable of interfacing with M&S tools, when necessary, even in real time. In particular, the system to be implemented should be able to perform at least the following functions:

- Creation of a neural network able to implement machine learning algorithms (e.g. classification algorithm).
- Neural network in feedback with tools used in M&S.
- Creation of special interconnection bridges between the neural network and the M&S tools in order to read/write specific data (stochastic variables) from the simulators. The APIs made available by the M&S tools could be exploited and/or a standard approach-based using the HLA protocol could be used.
- Automate the training process by populating the dataset (input) with the launch of multiple simulations in sequence and/or in parallel.
- Application of different machine learning algorithms on specific variables (output) to provide deductive results on new scenarios (different boundary conditions).

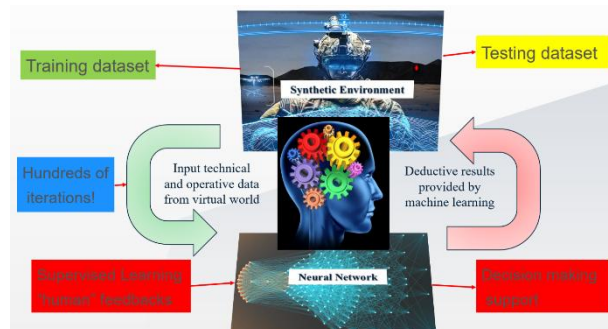


Figure 2: Basic visualization of the M&S and AI integration concept.

3. Main Components and role within architecture

The proof of concept to be developed should be versatile in order to implement different applications. It should be characterized by the following components:

- An Artificial Intelligence software structure, structured to be trained through different processes that can go far over the traditional Machine learning such as Deep learning and Reinforcement Learning. This element is essential not only because it will

drive the learning process and the consequent decision-making capability, but also because it will be in charge of running all the processes of the other pieces of the puzzle. In other words, it should be able to run the M&S tools automatically changing input parameters, reading the outputs of the simulation and then reiterate the process (even thousands of times) in order to have enough data for the learning to be reliable.

- Constructive/Virtual simulators for the implementation of military scenarios at different levels of use: strategic, operational and tactical. These tools fall into the so-called Computer Generated Forces (CGF) category and are essentially based on a database containing the main physical and doctrinal data of the simulated units. In addition, the aforementioned tools allow the generation of a virtual terrain, on which to define the synthetic environment, mainly by inserting vector files, relating to specific types of data defined for each layer of the terrain. In the simulation phase various factors are involved, which are related to the following features:
 - types of units defined in the organization of forces (Regiments, Companies, Platoons);
 - characteristics of the weapon and ammunition systems used.
 - characteristics of the sensors and equipment used.
 - types of military platforms according to the domain of use.
 - interactions of the aforementioned factors with the physical characteristics of the ground and with the external conditions (weather).
 - doctrinal models parameterized within the rules of engagement.
 - decision-making algorithms connected to autonomous actions of the units.

The CGFs are usually integrated with additional applications that allow analysis of the results, in terms of statistical data related to the mentioned features or to specific events that could be monitored during the simulation. Moreover, the computational logics of M&S tools are mainly stochastic since digital objects progressively manage probabilistic data (probability of hitting the target, probability of detection, percentages of efficiency and effectiveness of systems and units according to contingent situations, etc.).

- Simulators/Expert systems able to carry out calculations of a mathematical nature, based on models defined by programming. The models virtually reproduce the behaviour and the effects of specific natural or artificial events following relevant physical laws. The Simulators/Expert systems outcomes are used to build the characterizations of the different layers shared in the simulators' synthetic environment, with particular reference to propagative effects that can act on the different military domains.
- A standard interconnection protocol between different M&S tools to obtain a federated simulation is HLA (High Level Architecture) to exchange information in terms of objects' attributes (unit's geographical position, unit's composition, unit's attitude, etc.) and interactions (conflicts between units, attack effects, etc.).
- Application Programming Interface (API) used for the implementation of custom connections with the neural network, in terms of reading/writing the scenario's technical and operational data processed by the simulators.
- Database(s): Used to provide external source of information about terrain, weapon systems, logistics, effect of environment on units (e.g. CBRN agent), etc. These databases will also be used to store "experience", meaning selected data taken from the learning process to include information supported by AI.

As an example, running a simulation to study and analyse the number of soldiers killed in a given scenario, the distribution of the data will be used as input for the neural network that will interact with the simulator for the population of the dataset and reflect the information provided in the selected layer. Applying adequate training using standard technical-operational parameters and employing the appropriate machine-learning algorithms, the neural network will provide deductive results in order to obtain the best course of action to recommend to the decision makers. These results are subject to the classification of "events" performed and to the analytical situation defined in the assumptions of the simulations.

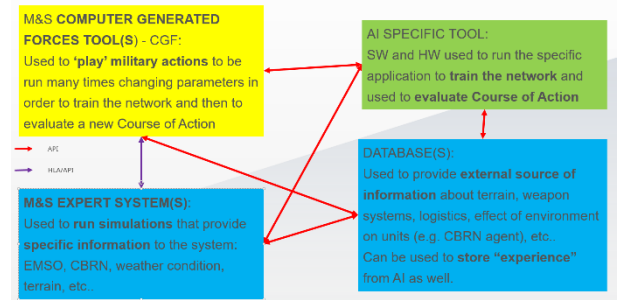


Figure 3: General architecture of the proposed proof of concept.

4. Use cases

In order to develop the proof of concept, an existing NATO M&S CoE project will be applied as a use case to perform the machine learning activities with a training dataset and testing dataset, consequently measuring the performance and output of the neural network interfaced with a simulation tool. A land and air tactical scenario will be tested in a mega city involving units, vehicles and robotic autonomous systems (RAS). In particular, the RAS parameters will be used to develop the deductive logic expected from the neural network, trained using both operational and technical data and carrying out the classification process with specific scores provided by the M&S tool. After completion of the neural network training, the best parameters' values, determined by the Neural Network, will be uploaded in the RAS and will allow it to run its mission with higher performance and better scores compared to the initial training condition of the network.

As mentioned above, additional use cases will also be carried out to determine the neural network's ability to provide optimization of units' and related sensors/systems' objectives while under the effects of two specific virtual layers. The idea is to exploit an Electro Magnetic Spectrum Operation (EMSO) and a Chemical Biological Radiological Nuclear (CBRN) scenario, suitably developed and characterized by temporal evolution of the technical parameters during the simulation. Therefore, in the presence of chemical contamination on the battlefield, the neural network is expected to provide guidance for the optimal path to follow, exploiting the training carried out on the deduction of distribution variability contamination, depending on specific scenario conditions and the supplied equipment.

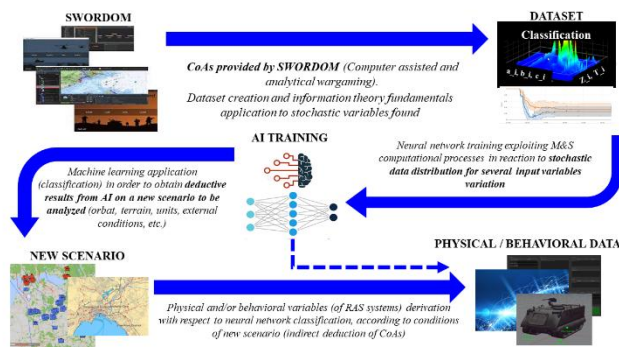


Figure 4: layout of the first use case on Robotic Autonomous System.

5. Proof of concept building blocks

The system architecture developed for the proof-of-concept execution is composed by the following elements:

- M&S CGF tools: Used to run military actions several times, changing parameters to train the network and then evaluate different Courses of Action, one by one. First tests will be performed using MASA SWORD due to its high flexibility and the possibility to use High Level Architecture (HLA), Application Protocol Interface (API), C# and Python. Subsequently, further testing with JTLS, VBS4 and additional simulators will be performed. The NATO M&S CoE's WISDOM platform will also be used to visualize results and to enhance information sharing.
- AI specific tool: SW and HW used to run the specific application to train the network and evaluate Courses of Action. MATLAB will be used to run this activity.
- M&S expert system(s): Used to run simulations that provide specific information to the system such as EMSO, CBRN, weather condition, terrain, etc. These systems will be chosen depending on the use case (STK, MATLAB/C# for EMSO applications and HPAC, ALOHA, HOTSPOT or other diffusion tools for CBRN applications).
- Database(s):

All elements will be enabled to share information with HLA as a first option, and API as an alternative, in order to allow complex info-sharing such as those involving CGF and AI tools.

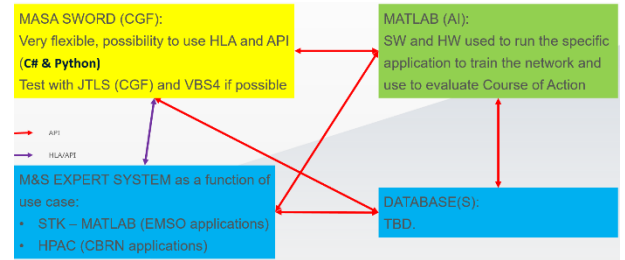


Figure 5: Elements of the specific architecture of the proposed proof of concept.

6. First milestone Of the Architecture: The Main Bridge

In order to develop the architecture, the first and essential element to be built is the “bridge” that enables the M&S tools to interact with the AI tool. It is also a quite complex activity, considering that many simulators are not structured to easily share data related to performance or provide “scores”, useful to understand what the effects are of changing specific value within the set of data available (Orbat, missions...).

In order to allow effective information sharing, specific software socket requirements have been identified to allow MASA SWORD as the first CGF sharing information with the AI tools. SWORD has been chosen for its flexibility in terms of data availability and for the use cases already available.

Subsequently, a similar procedure will be applied to the other CGF tools.

7. API Project For the MASA SWORD data extraction/insertion

The challenge was to create a procedure to exchange data between the M&S tool (the “socket”) and the AI system (the “spine”). The solution was to develop a client script, which exploits a SWORD API in C#, able to read and write simulation data from an exercise. The exchange of information is built in two macro-areas: data reading and data writing, in order to train a neural network for classification purposes and to provide deductive results. Currently, the M&S CoE has conceptualized the data-reading phase as described in the following paragraph.

8. Structure of the MASA SWORD Socket

A root folder will be created by a client script for each exercise. In this folder the so-called common files will be stored, which can affect all forces' factions (terrain.xml, weather.xml, physical.xml).

Moreover, a folder created by client script for each automata will be stored as well. In the automata folder, a folder created by client script for each unit will be stored, containing the information of the unit itself and its equipment.

At simulation tick zero (initialization phase), an xml formatted file with the following fields will be found:

- Time (tick)
- Diplomacy
- Hierarchy
- Status (strength)
- Unit type
- DIS type
- Properties:
 - Fuel
 - Ammunition
 - Sensors (type and punctual probability of detection)
 - Weapons (type and punctual probability of detection)
 - Crew (dead/wounded)
 - Human factor (tired, veterans, etc.)
- Interactions
- Reports
- Mission
- Posture
- Terrain layer (only for land units) → modifiers (useful for having sensors and weapon probability of detection)

After the tick zero initialization file, all fields of the unit will be formatted in the xml file. To avoid a huge amount of data during the polling at each simulation time, an xml file will be created containing only the units' updates, in the same units' folder, as the test solution. In this root folder, the results folder, created by the client script containing the COAs data in csv format (time vs value), will be stored. This piece of information will be used by the neural network for classification.

9. Scenario generation

A different and complementary application that will be studied in the future and also applied to Wargaming, is the possibility, after proper training, to automatically generate scenarios, including new ORBATs. This solution could be used for:

- Training sessions.
- Operational scenarios fed with real data (i.e.: open-source data, intelligence, etc.).

- Conflict simulations among different parties feeding the other AI-driven M&S.

This application is closer to those already applied by the very familiar and widespread use of AI such as ChatGPT. From this perspective, it will be possible to adapt to an already developed commercial application. An interesting example is the set of tools developed by MATHWORKS for MATLAB. They are applied to automatically develop entire projects with minimal guidance/input from human beings. The complexity of such an application is similar to the one under evaluation and, therefore, could be a good starting point.

10. Conclusions And Next Steps

The proposed concept, and related proof, is very promising and no similar project has yet been identified in international literature or within the AI and M&S Community of Interest. Nevertheless, it is a challenging endeavour that will face many obstacles in the development phase. For this reason, within the system architecture, the M&S Tool socket and the complementary AI tool plug, will be developed to initially test their effectiveness using the available software and a standard PC with a full MATLAB license installed. Preliminary tests, using a simplified version of the training structure, will be conducted to verify its results. Afterward, when the whole framework is available, the SW package will train the neural network and develop the desired decision-making support tool.

Using MATLAB, able to create new SW components from scratch using generative AI, the proof of concept will then be validated through testing of new scenarios and ORBATs, employing a limited amount of data, for final capability development. Afterwards, the use cases will be developed one by one, depending on the availability of the architecture's components.

11. About the author

Author Name LTC (ITA – OF4) Piergiorgio Ventura graduated in physics in 1998 with a specialization in Nuclear Physics. He then joined the Italian Army in 1999 with the rank of Lieutenant and began working within experimental firing ranges where missiles, weapon systems and ammunition were tested. After earning a PhD in quantum electronics and plasma physics in 2010, where a remote sensing detection system to detect and identify chemical compounds, based on optical detection, was developed, he started working in the CBRN field for research, testing and procurement activities. Since January 2022, he has served as the M&S Concept Development Section Chief at the NATO M&S

COE, where he is working to develop new concepts using his expertise.

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CASTLE (CBRN Activities Simulation Total Layer Environment), CBRN Activities Within Modelling & Simulation

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1. Introduction

Modelling & Simulation in support of CBRN and Environmental Protection has not been fully exploited to its maximum potential within the M&S areas; namely, Education and Training (Exercises), Support to Operations, Planning (Course of Action Analysis), Execution (Decision Support), Mission Rehearsal, Concept Development & Experimentation (CD&E) and Procurement. Many CBRN tools already exist, such as those providing models to simulate the dispersion of CBRN Agents, or the wearing of IPE during training. However, a comprehensive approach to maximize its effectiveness is still missing.

The CASTLE (CBRN Activities Simulation Total Layer Environment) project is an innovative approach, which integrates existing tools and provides those not yet developed. It represents a powerful M&S asset to fill the gap in this military problem. This concept was described in detail in the 2023 Report and related I/ITSEC 2023 paper.

ALOHA and HOTSPOT dispersion simulation tools for the CBRN agent are part of the CASTLE architecture and the NATO JCBRN CoE HPAC data were included in the testing activities. CASTLE consists also of MASA SWORD and VBS4 as CGF (Computer Generated Forces) tools. The scenarios are built to simulate a synthetic CBRN environment with contamination and diffusion data. Several tests have been performed to verify the possibility of integrating all components of the architecture using an ad hoc Application Protocol Interface (API). The final objective is to test the CASTLE capability of providing the Commander with a comprehensive synthetic visualization of the CBRN framework on the battlefield.

2. Project Of The CBRN Layer

The idea is to share all “expert systems” available CBRN events data with the Computer Generated Forces (CGF) M&S tools, including external ones for specific calculations (modelling of sensors, protective equipment, etc.).

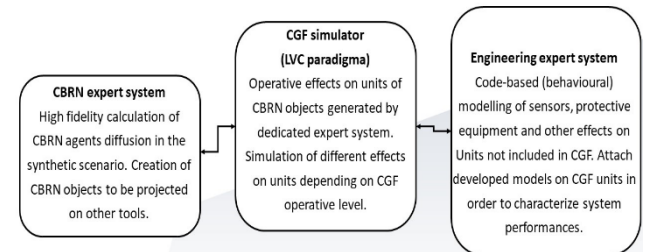


Figure 1. CASTLE project general concept.

Starting from this objective, proof of concept has been developed.

The tools used for this purpose are as follows:

Expert Systems (ES):

- ALOHA (Chemical events).
- HOTSPOT (Radiological and Nuclear events).
- HPAC (all CBRN events) – files provided by NATO JCBRN CoE.

Computer Generated Forces (CGF):

- SWORD – MASA Company – Operational level.
- VBS4 – Bohemia Interactive Simulation – Tactical Level (tentative).

Wargaming platform and as “bridge” from ES to CGF:

- WISDOM.

High Level Architecture (HLA) federation:

- PITCH RTI.

The links used from ESs to WISDOM are Application Protocol Interfaces (API).

Some of the Expert systems and CGF have been used also as Engineering expert system, considering that elaborate data such as the people affected were already calculated within specific branches of the algorithms.

The following is a description of the tools included in the CASTLE architecture:

HOTSPOT

The HotSpot Health Physics Codes, or HotSpot program, developed and regularly updated by the USA National Atmospheric Advisory Center (NARAC), provides a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. It was created to equip emergency response personnel and planners with a fast, field-

portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling radioactive material.

This program is designed for short-range (less than 10 km), and short-term (less than a few hours) predictions.

ALOHA

ALOHA®, developed and maintained by the USA Environmental Protection Agency (EPA), is a hazard modelling program which is used widely to plan and respond to chemical emergencies. It allows you to enter real or potential chemical release detailed data and then generate threat zone estimates for various types of hazards. It also models toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, pool fires, and vapour cloud explosions.

The threat zone estimates are shown on a grid, and they can also be plotted on maps in MARPLOT® (Mapping Application for Response, Planning, and Local Operational Tasks), Esri's ArcMap, Google Earth, and Google Maps. The threat zone depicted in red represents the worst hazard level, and the orange and yellow threat zones represent areas of decreasing hazard. The results are a static image after one hour.

HPAC

HPAC, owned by Defense Threat Reduction Agency (DTRA), models and predicts human collateral damage for events involving intentional or unintentional release of chemical, biological, or nuclear materials into the atmosphere or enclosed space. It provides a suite of models for simulating the release of CBRNE materials into the atmosphere and their associated dispersion using detailed meteorological information. These predictions are used to estimate the effects of these CBRNE agents on the physical environment and, to a lesser extent, the resulting impact of that release on an exposed population. It can describe the transport/dispersion of hazardous materials through the atmosphere due to attacks or accidents resulting in radiological, chemical, or biological releases. It uses information on the material source, the amount released into the atmosphere, high-resolution weather forecasts, and particulate transport to model the hazard areas produced by such events.

WISDOM

Over the years M&S COE has developed WISDOM, a software tool for the configuration of geographical scenarios. This platform is particularly suitable to carry out Wargaming activities and is aimed at those who need to perform education & training activities, experimentation, AAR or preparation for real missions, both in the military and civilian context. The platform is designed to reuse and tailor available scenarios or to develop new scenarios in the tactical, operational or strategic level. Due to its state of the art architecture, WISDOM allows wargamers around the globe to access the platform from their location as it is built to support distributed execution. The MSCOE is presently upgrading WISDOM flexibility and integration capability with M&S tools and is used in this project as bridge between ESs and CGFs. For this purpose, a specific HLA plugin has been implemented to share entities with M&S platforms even without a time management process.

SWORD

SWORD, developed by MASA Company, is a suite dedicated to staff education and training, which includes a scenario building application, an aggregate simulator and an analysis tool. Its main purpose is within the training environment, but it also supports planning and education. SWORD allows aggregate-level simulations for tactical training, which is oriented towards operational field decisions. It is normally used at Operational level; it has an HLA plugin and is compatible with several languages including C#. Lastly, it has several embedded CBRN features and is able to share them with HLA, making it a very versatile platform, easily adaptable to receive and share information with other systems.

VBS4

VBS4, developed by Bohemia Interactive Simulations, is a whole-earth virtual desktop trainer and simulation host that allows you to create and run any imaginable military training scenario at tactical level. The VBS4 workflow steps the user through Prepare - Execute - Assess phases, facilitating fast and effective skills enhancement. In VBS4, users create "Battlespaces" that are a collection of terrain edits, mission plans, scenario files and after-action reviews. With VBS4, you can plan your mission, build your terrain with easy-to-use interfaces, and focus on the learning points of the exercise rather than the technical aspects of setup. It has several embedded CBRN features, and it is able to share them with HLA. It is therefore a good platform to adapt to receiving information and share with others.

PITCH RTI

The product Pitch pRTI™ is an implementation of the IEEE 1516 Interface Specification. It lets you integrate simulations in an HLA compliant way. You can mix different operating systems and programming languages. It gives you the ability to integrate your existing C/C++ simulators with platform independent Java systems. Pitch pRTI™ provides APIs for both C++ and Java, so you can use federates written in any of those languages together in the same federation. It provides advanced debugging capabilities. It has an extensive GUI that allows you to inspect the state of your federation during runtime as well as a powerful set of debugging tools.

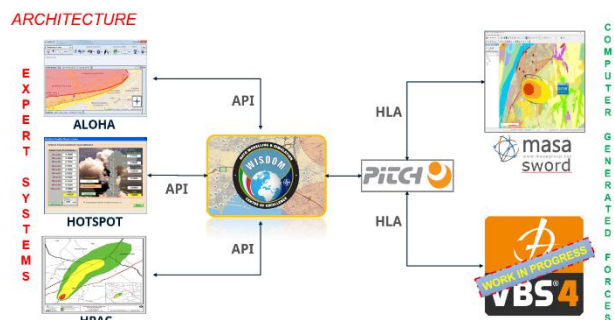


Figure 2. CASTLE project architecture developed during 2024.

3. Proof of concept development

The CASTLE project has completed its concept development phase, and proof of concept has been delivered. It consists of a series of simulations performed by HOTSPOT and shared within the architecture (event shown in figure 3). Using WISDOM as an HLA bridge, the contaminated area is shared on SWORD and in this specific example, HOTSPOT generates a Plutonium contamination cloud already existing in its database.

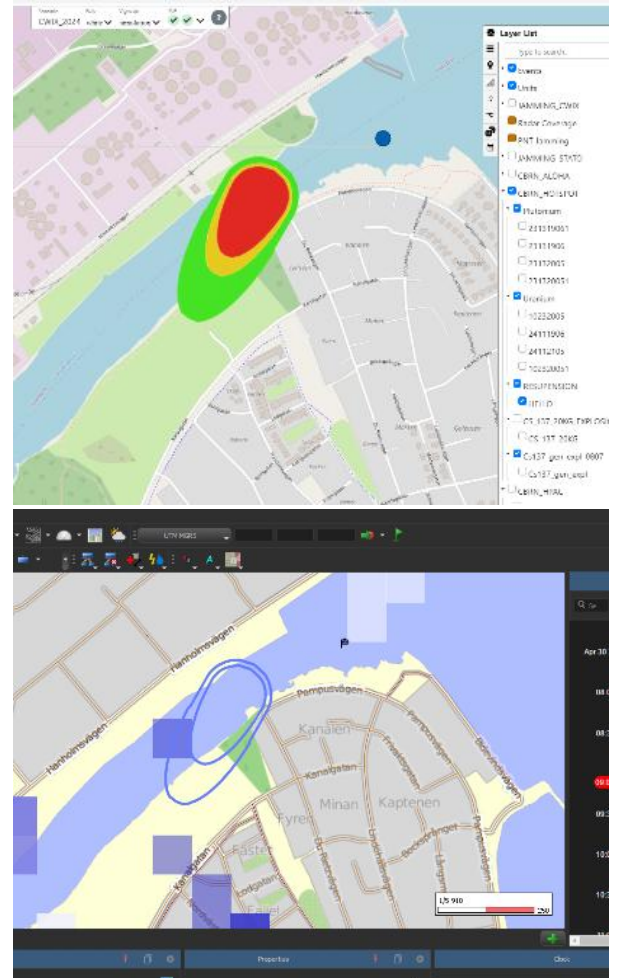
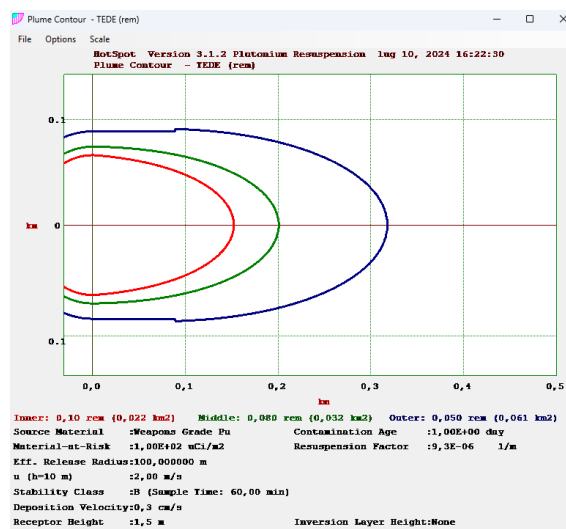


Figure 3. Plutonium plume shared from HOTSPOT (left) through WISDOM (center) to SWORD (right).

ALOHA is included in the proof of concept too as “expert systems” for chemical events. An example of the events used for the test is SARIN contamination shown in figure 4. Also, in this case the event is imported from ALOHA to WISDOM and then shared using HLA with SWORD.

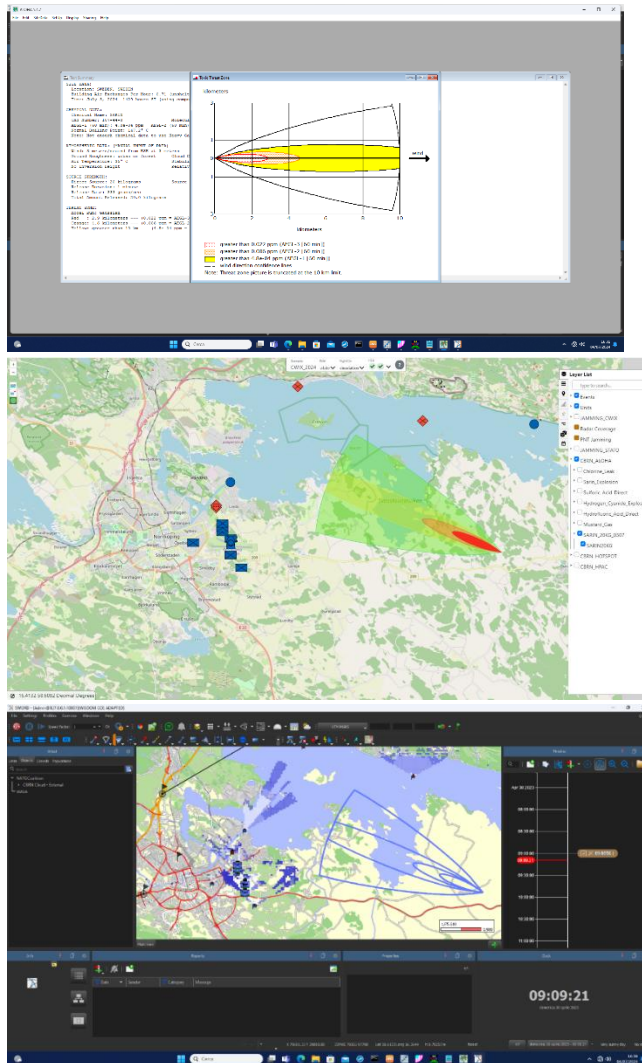


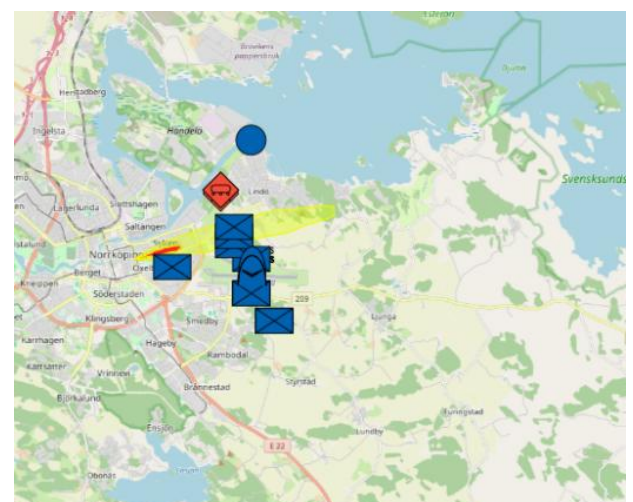
Figure 4. Sarin plume sharing from ALOHA (up-left) through WISDOM (up-right) to SWORD (down).

The use of HPAC is not directly included in the proof-of-concept architecture. However, the HPAC files integration capability has been verified using data directly provided by the NATO JCBRN CoE and therefore the tool can be used as “expert systems” for any kind of CBRN events too. The testing was conducted with a simulation of a SARIN contamination imported on the WISDOM database and, in this case, evolved over time. The results of the experiment confirmed that the architecture was able to share the files with SWORD using HLA. The three steps of the evolution over time are shown in WISDOM (figure 5 up) and the equivalent in SWORD (figure 5 down).



Figure 5. Sarin plume sharing from HPAC evolving over time in WISDOM (up) and shared in SWORD (down).

The following figure shows a biological example (Anthrax) of diffusion generated by HPAC and shared by WISDOM to SWORD through HLA.



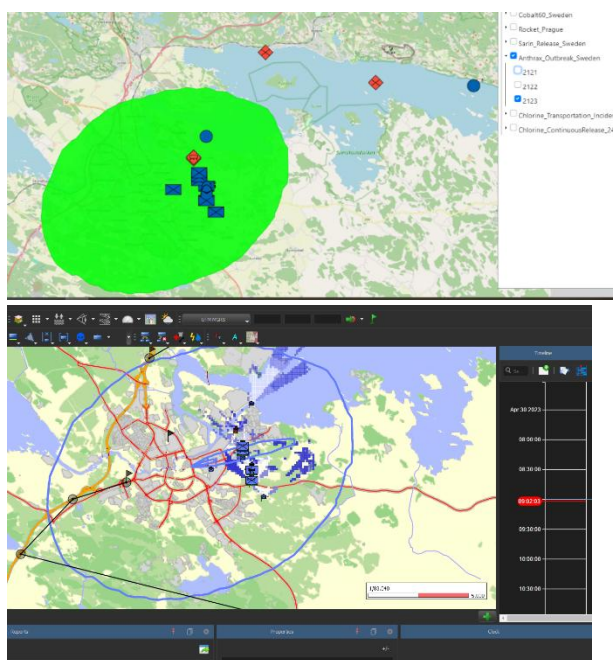


Figure 6. Anthrax plume sharing from HPAC evolving over time in WISDOM (left) and shared in SWORD (right).

4. Future activities

The CBRN and M&S integration project (CASTLE), conducted using the available tools at the MSCOE and performing the testing activities described in this report, confirms that the initial Concept is valid, and the developed architecture is effective. The project has completed its first phase of experimentation as planned in the MS COE program of work (POW) and the next one will be conducted in 2025 with additional interoperability tests and an architecture implementation as follows:

- Interoperability tests with additional Computer Generated Forces, starting from VBS4 in order to represent CBRN data on a tactical simulator (FOM adaptation might be required).
- Assess the “CBRN effects” realism processed and delivered by the Expert System (HPAC, HOTSPOT) or internally by Computer Generated Forces tool.
- Assess the NETN FOM capability to take into consideration the CBRN effects (as an example, all the CBRN events represented in SWORD are presently “CBRN cloud external”) and propose modification and/or integration to the NMSG standardization community, if required.
- Include an Engineer Expert System in the architecture to cover specific CBRN effects (e.g. filter duration).
- Include C2 Systems in the architecture to increase interoperability capabilities of the project.

The MS COE is exploring the possibility of conducting parallel activities linked to the CBRN project involving additional stakeholders from the M&S/CBRN community of interest (COI) as follows:

- foster cooperation with other institutions to integrate their activities in one broader project, bringing all the stakeholders around the same table, sharing the existing resources and analyzing additional capabilities with the objective of developing a comprehensive CBRN Layer, capable of providing effective decision-making support to the Alliance.
- Test individual capability and the whole architecture for the verification and validation process.
- Make the delivery available to the entire COI and to NATO in order to obtain the maximum benefit for the Alliance and improve the tool itself through users and developers contributions.

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The principal theme for the conference was:

'Enabling multi-domain operations through M&S'

Through team effort at the M&S COE we have captured the articles from the CA2X2 Forum allowing our readers to reference the great work done by some of the contributors.

Please use these articles as inspiration for further collaboration and contributions to these important topics.

*Thank you for the contributions to the forum,
the insightful questions and discussion to advance these topics.
For those that were unable to participate, this collection of articles will help you understand
the level of expertise and professionalism that was displayed during the forum.
Enjoy.*

If you wish to provide feedback, please send it to us at: info@mscoe.org.

*Thank you and good reading!
The NATO Modelling and Simulation Centre of Excellence*

A Bottom-Up Approach To The Simulation Of Multi-Domain Operations

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Abstract

The NATO definition of multi-domain operations (MDO) describes the creative interplay between activities in multiple domains aimed at achieving an advantage by pressuring the adversary's decision-making process. Studying this interplay is the domain of simulation, and capturing MDO in computational models may lead to opportunities for rich training and CD&E applications. However, given the nature of MDO, no one-size-fits-all simulation approach thus far exists. Therefore, instead of fitting the definition of MDO into a simulation environment, we aim to enrich the simulation environment towards the MDO philosophy instead. In this paper, we describe the application of the practical essence of MDO by using a bottom-up approach and outline how state-of-the-art simulation and artificial intelligence technology can be connected to creating and executing rich MDO scenarios.

In our approach, we put the LLM in the center as a computational tool which we use to orchestrate tactical simulators. Such tactical simulators offer precise control over simulation starting conditions and effects, while the application of LLMs provides coherent automatically generated and evolving narratives and courses of action. The possible courses of action follow from the capabilities of the entities in the simulation environment, leading to scalable MDO simulations. Putting together, a decision-maker using the simulation for MDO practice can be immersed in a rich interconnected world with minimal effort from scenario builders.

1. Introduction

The Multi-Domain Operations (MDO) concept has become increasingly relevant to making sense of modern warfare. However, the definition of the concept is descriptive instead of prescriptive and the arguments on “how” multi-domain operations is going to deliver its promises, can be seen as unclear or not

entirely convincing (Ellison & Sweijts, 2024). In order for the MDO concept itself to progress, it needs to be experimented with. As mentioned by Phillips (2023) about MDO: “we need to go from the thinkers to the doers”. This paper continues this train of thought by applying Modelling & Simulation (M&S) methods to MDO in order to increase our understanding of the concept.

This paper will introduce a *bottom-up approach* to the simulation of MDO, in the form of a framework in which pieces of simulation technology are combined in order to analyze military decision-making. The framework utilizes a selection of complementary simulation components and concepts in order to create a simulation environment in which MDO elements can be simulated. The bottom-up approach aims to create an open-systems design towards the simulation of MDO scenarios in order to rapidly create a MDO simulation environment.

MDO encompasses intangible elements such as non-military activities, which make it a complex concept. MDO can be seen to bridge the gap between political and military strategic goals. The orchestration of these non-military and military activities is an important element of MDO (Reynolds, 2022). Our research focusses on analyzing the impact of military decision-making on other non-military and military entities. In order to restrict the complexity of the simulation environment, our approach confines the effects being made only by military decision-making. The goal of this research is to provide a simulation framework that can support the development of effective MDO strategies, and to enhance the understanding of the impact of military decision-making in complex, dynamic MDO-enabled environments.

The research is presented in the following sections: Section 2 outlines the framework used to simulate the effects of military decision-making in an MDO-enabled environment. Section 3 presents an application of the simulation framework. Section 4 addresses the challenges encountered in our approach and explores potential future work. Section 5 concludes the paper.

2. A framework for MDO-enabled simulation

In this section, the framework for MDO-enabled simulation is presented. Section 2.1 provides an overview of the framework. For ease of discussion, the

framework is divided into three components: A, B, and C. The function of component A is the generation of a rich narrative, given an initial scenario describing military entities and associated military objectives (section 2.2). Component B is the framework and “simulation loop”, where a decision-maker is responsible for observing the simulated environment, orienting themselves to possible courses of action, and deciding on the next actions to take in the simulation (section 2.3). The goal of component C is to provide decision support to the decision-maker (section 2.4). We conclude the section with a discussion of other simulation components that may be included in a future version (section 2.5).

The version of the framework presented in this paper focusses on the effect-based reasoning element of MDO. Other elements such as orchestration and synchronization are considered out of scope but are relevant to research in the future. Furthermore, to keep the framework feasible, we dramatically restrict the possible effects that can be selected to six actions which will be explained in the remainder of the section.

2.1 Overview

Figure 1 shows an overview of the framework. The “bottom-up approach” is represented in the framework by the combination of the different technologies to obtain a simulation environment suitable for supporting MDO decision-making.

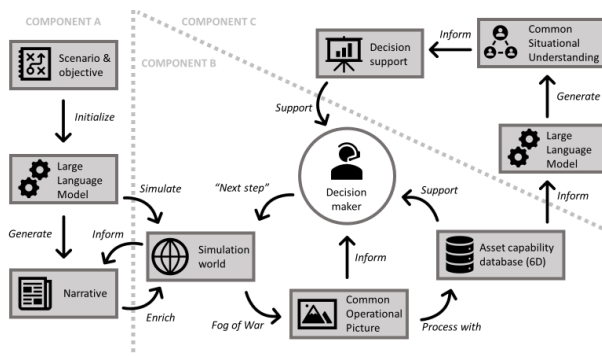


Figure 2. Overview of the framework

Framework by the combination of the different technologies to obtain a simulation environment suitable for supporting MDO decision-making.

2.2 Component A: Start of simulation world

As with many simulation activities, use of the framework starts with a definition of a scenario and the accompanying objectives that should be attained in

the scenario. As a first step towards a rich MDO-enabled environment, the scenario and the objectives are fed to a Large Language Model (LLM). LLMs are artificial intelligence (AI) models aimed at human-like natural language processing. The LLM is asked to generate a narrative, a cohesive story in which the military entities defined in the scenario play a role, based on the scenario objectives. For example, if the scenario defines a blue force tank and a red force building, with an objective for the tank to destroy the building, the LLM is asked to invent a story about the two opposing factions, containing, e.g., the events that led up to this confrontation. Based on the scenario and the narrative, the LLM generates configuration files which describe the placement and specifics of each entity. In this manner the LLM can automatically instruct tactical simulations to generate a high-fidelity simulation world. The tactical simulation can then calculate how the situation unfolds. Changes in the simulation world are fed back to LLM to inform its next decisions.

Component A can be seen as an interactive exchange between the operator and the framework. The operator can construct the scenario and define objectives either by providing a broad prompt that outlines the scenario, or by incrementally building it. In the latter approach, the operator can place buildings, deploy forces, and make other adjustments step by step, using a conversational style to shape the scenario.

2.3 Component B: Simulation Framework

The simulation loop starts by filtering the information from the “ground truth” simulation world. This way a common operational picture (COP) can be established. The information filter represents the fog of war, as military decision-makers do not always have access to complete information to inform their decisions. The decision-maker, central to the framework, has the task of selecting actions in order to reach the objective of the scenario. In support of fostering the MDO mindset when selecting an action, we introduced a new simulation component called the asset capability database. The goal of this database is to inform the decision-maker about various actions that are possible with their assets (soldiers, vehicles, etc.) in the simulation world.

The decision-maker interacts with the simulation world by issuing one of the six possible actions inspired by Grant (2023), hereinafter referred to as 6D. The

6Ds are detect, deny, degrade, disrupt, destroy, and deceive. While these 6D originate from cyber operations, they offer a solid starting ground for the first iteration of the framework. By using the 6D concept in combination with the asset capability database, we can translate the decision-maker's action into a concrete simulation instruction. To fit our framework this paper defines the 6D as follows:

- **Detect:** discovering or identifying the presence, location, or characteristics of an enemy.
- **Deny:** preventing or restricting the enemy's use of a specific asset, area, or capability, without kinetic means.
- **Disrupt:** interrupting or interfering with the enemy's operations, plans, or systems without kinetic means.
- **Deceive:** intentionally misleading or manipulating the enemy's perception, decision-making, or actions without kinetic means.
- **Destroy:** completely eliminating or rendering an enemy's capability, asset, or installation inoperable with kinetic means.
- **Degrade:** interrupting or interfering with the enemy's operations, plans, or systems with kinetic means.

Entities in the simulation world are automatically classified in the asset capability database as classes (e.g., M1 Abrams as "Tank", harbor as "infrastructure"). The asset capability database specifies how classes can interact with each other (e.g., an attack helicopter cannot detect or destroy an AWACS, yet the AWACS can detect the attack helicopter but not destroy it). This information is stored for all classes and subsequently shared with the decision-maker and LLM.

In a typical simulation loop, the decision-maker interacts with the simulation in a turn-based manner. They consult the COP and the capability database to evaluate possible actions, then select and submit an action along with the relevant entities to the simulation world, which calculates the effects. The COP is updated with the results, and this cycle repeats until the end state of the scenario is reached. After each turn, the changes that happened in the simulation world are fed to component C.

2.4 Component C: Common Situational Understanding concept

The Common Situational Understanding (CSU) concept is developed in order to enhance the understanding of the decision-maker about the impact of their actions on the simulation world. By understanding the impact of each action, one can compare the outcome of each action and evaluate which outcome is most beneficial for the desired goal. By doing so, it enhances the understanding of which MDO effects deliver the desired end state and enables the opportunity for non-military effects to contribute to reach this end state.

The asset capability database is used by LLM to generate the CSU about the situation that is unfolding in the simulation world. The CSU concept makes use of established descriptors for both tangible and intangible elements, using the PMESII/ASCOPE matrix to categorize entities in the simulation world. PMESII (Political, Military, Economic, Social, Information, and Infrastructure) defines the intangible context in which entities operate, while ASCOPE (Areas, Structures, Capabilities, Organizations, People, and Events) defines the tangible aspects of each entity. The LLM describes the situation based on these descriptors and provides "what-if" scenarios to predict how certain actions might impact the simulation. For example, a howitzer destroying a bridge has a different effect on the PMESII/ASCOPE matrix than a fighter jet denying a section of air space. By capturing this reasoning in a single overview, the framework aims to form the foundation of a MDO decision support tool. As noted by Kodalle et al. (2020), the use of the PMESII/ASCOPE concept allows for structured problem analysis without oversimplifying its complexity.

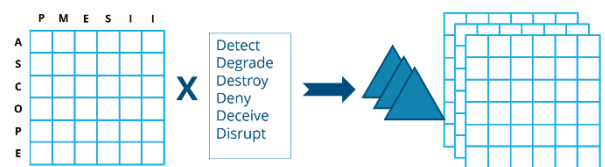


Figure 2. Common Situational Understanding concept

As discussed in section 2.3, we consider six types of actions which the decision-makers can undertake with their assets in the simulation world. The CSU concept processes each possible action that can be taken to reach the desired goal. Each pair of actions and entities creates a different expected change (delta) in the PMESII/ASCOPE matrix, this is shown in Figure 2. By

presenting the expected changes, the decision-maker can derive decision-support from the CSU concept.

In order to classify which outcome is most beneficial, the decision-maker can evaluate the impact on each element of the CSU concept. For example, the decision-maker can then choose an action that has no negative consequences on the Economical-People element to ensure economic stability in a local area. The action that results in the most beneficial outcome compared to the decision-maker's goal can then be chosen.

2.5 Extensibility with other simulation concepts

The framework's open-systems design supports the development of simulation concepts, such as cyber and cognitive simulation tools. For example, in the case of cyber simulation the LLMs capability for coherent scenario generation may be advantageous. Cyber operations typically involve numerous entities within a cyber infrastructure, such as a country's internet network with many cyber actors. Generating this level of complexity with a vast number of entities can be time-consuming. However, utilizing the LLMs in the framework can streamline the creation and placement of these entities, allowing for the development of more complex and realistic simulated worlds.

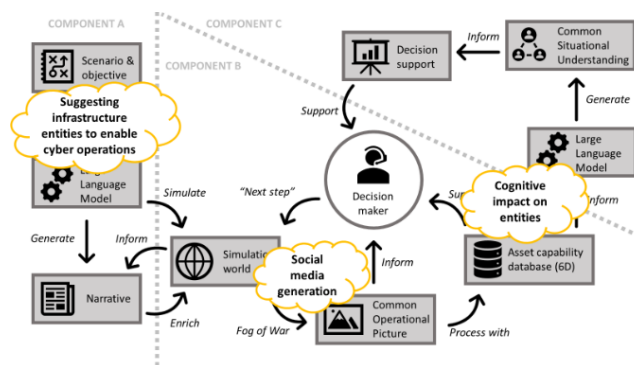


Figure 3. Extensibility of the framework

world, social media can influence political strategic objectives by shaping public opinion. To enhance the simulation environment, a social media simulator can be integrated. Amghane & de Marez Oyens (2024) present such a tool, capable of generating realistic social media posts that reflect events occurring within the simulation. Incorporating such a simulator can also increase immersion for decision-makers when using the simulation for wargaming scenarios. See Figure 3 for where the framework can be extended upon.

3. Application of the framework

We experimented with the framework creating a proof-of-concept version of it and using a fictional scenario. The scenario involves two near-peer adversaries on the verge of war, with only hours remaining before hostilities erupt. Both sides feature military and non-military institutions, political figures, infrastructure, and civilian populations. Each side is permitted to take offensive or defensive actions using the resources and entities at their disposal.

The proof-of-concept was developed based on the components described in Section 2 to demonstrate the feasibility of leveraging LLMs to reason over the possible effects of military action on the non-military entities in a scenario, akin to a wargame adjudicator. The system comprises three core components: a data structure for keeping track of entity-level state information, an assets capability database to restrict inter-entity interactions and an LLM, functioning as a world model. In the proof-of-concept no tactical simulations are connected, instead we used an LLM as its primary computation tool. The LLM is used to process actions for all entities that are present in the simulation world. Inspired by results of Chuang et al. (2024), military and non-military entities are simulated in a similar manner using the LLM.

When a military action is chosen by the decision-maker, that action is communicated to the LLM as a textual input of the form "Instruct X to carry out ACTION on Y" or "X detects/destroys/degrades/... Y" along with the state of the scenario, which includes the name, location, status, allegiance (force) and description of each military and non-military entity present in the scenario. These entities are categorized according to the PMESII/ASCOPE matrix, as explained in the CSU concept in section 2.4.

Upon receiving an action and states of each entity in the scenario, the LLM is invoked to advance the state of entities. Based on its extensive world knowledge and assets capability database, the LLM judges whether an entity would be affected by the simulated action and modifies the status, location and description of the entity accordingly. We intend to include tactical simulations for this in future work.

In order to incentivize the LLM to come up with sensible continuations of the input scenario, a variety of prompt engineering techniques were used to craft two interrelated LLM prompts. The first prompt,

hereafter referred to as the *system prompt*, serves to establish the role and expectations of the LLM as a wargame adjudicator. This prompt explicitly defines the task of determining the effects of events and actions on entities within the scenario, while also emphasizing the importance of concise and relevant responses.

The second *instruction prompt* provides the necessary context, entities, and actions for the LLM to assess and respond to. This prompt incorporates a formatted list of entities, including their name, description, allegiance (force), location, and status, as well as a description of the action to be adjudicated. By carefully designing the structure and content of these prompts, plausible responses are elicited from the LLM, which simulate the effects of military intervention induced on the entities in the scenario.

At the time of writing, we are testing the proof-of-concept in a CD&E setting to test its limitations and strengths. Results will be detailed in a future publication.

4. Challenges and future work

A key challenge in the framework is validating the output of LLMs. The framework aims to focus on an asset capability database to calculate critical events within the simulation environment. This ensures that the results of these events are validated independently of the LLM's output. Intangible events generated by the LLM could be validated by using open-source data. For instance, platforms like data.worldbank.org, worldpopulationreview.com, and globalfirepower.com can provide real-world values for the PMESII/ASCOPE matrix. Weissenberger (2024) has demonstrated that such open sources can estimate PMESII values that are comparable to those provided by SMEs. While it is challenging to fully validate all LLM outputs, it is important to assess the degree of validation required. If the LLM's output does not significantly influence the simulation's outcome or compromise its core objectives, a more flexible validation approach may be appropriate.

The step-based simulation design of our framework makes it well-suited for wargaming applications in planning or training settings, where the validation of LLM outputs may be less critical. While high-fidelity simulators are not always required for wargaming, the framework's capabilities for entity and narrative

generation offer significant value. These features enable the creation of immersive, dynamic scenarios with greater complexity, enhancing the realism and engagement of wargaming experiences. In future research, we intend to further explore and refine the application of our framework in wargaming contexts.

The decision-support component is an intricate element of the framework. Currently, it functions in a basic manner by tracking which domain or dimension the decision-maker tends to prioritize. If one domain or dimension is used significantly more than others, the decision-support tool alerts the decision-maker. To enhance its effectiveness, we aim to further leverage the output from CSU analyses to provide more targeted and insightful assistance in the decision-making process. Since the CSU analyses generate large volumes of data, the decision support tool's role is to distill this information and customize it to meet the decision maker's specific needs. By doing so, we aim to offer the most effective support possible. Our ultimate goal is to develop the decision support system to a point where it can simulate human-like reasoning by expanding both CSU analyses and LLM capabilities.

5. Conclusion

The concept of MDO has gained significant traction in recent years, yet there remains uncertainty about how it will fulfill its promises. In order for the MDO concept itself to progress, it needs to be experimented with. The primary aim of this research is to deliver a simulation framework that can support the development of effective MDO strategies while deepening the understanding of how military decision-making influences complex, dynamic MDO-enabled environments.

This paper has introduced a framework for simulating MDO using a bottom-up approach that integrates various simulation components and concepts, creating an environment for analyzing military decision-making. The framework leverages LLMs to generate both simulation environments and narratives, while also calculating logical outcomes using an assets capability database. Additionally, it incorporates a CSU concept and decision support component that provides decision-makers with insights into the potential effects of their actions.

The paper also identified several challenges and future directions, including the validation of LLM output,

wargaming application, and the refinement of the decision-support system. To overcome these challenges, we plan to further explore the application of our CSU concept, integrate LLMs more effectively, and utilize open-source data for validation purposes.

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Seeding Success: Generating Valid And Realistic PMESII Start Values For Serious Wargames And Simulators

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Abstract

PMESII (Politics, Military, Economic, Social, Information, and Infrastructure) framework is widely accepted as parameters to judge and measure the condition of a country.

The success of each serious wargame and simulator depends, among other things, on the right starting conditions. Especially in the field of serious military wargames, it can be difficult to obtain realistic data about the condition of a played country. Therefore, data from free available sources and the weighting and processing of this data could be immensely helpful to generate realistic starting values.

Using open-source databases and the method of cross-impact weighting will increase the reliability of generating PMESII start conditions for wargames and simulators.

Keywords: PMESII, wargaming, simulation, cross-impact analysis, open-source.

1. Introduction

1.1. Background

In military training and simulation, creating realistic scenarios is fundamental for effective preparation and strategic readiness. Such realism allows for accurate assessment and decision-making exercises that mirror potential real-world conditions, preparing military personnel for complex operational environments.

1.2 Purpose of the Paper

This paper presents a novel approach for deriving realistic PMESII (Political, Military, Economic, Social, Information, Infrastructure) starting values using open-source data. By leveraging accessible and reliable public databases, this method aims to provide a robust

alternative to traditional sources like intelligence reports or subjective expert opinions, which may be limited, classified, or subject to bias.

1.3 Paper Structure

The paper is organized into seven sections. Following the Introduction, the Motivation section addresses existing challenges in PMESII data acquisition. The PMESII Framework section explains each component's role in strategic simulations, while Methodology describes the data sources and the PMESII-Generator. Verification and Validation outlines the expert survey and results analysis. The Discussion explores the findings' implications and limitations, and the Conclusion summarizes key insights and proposes areas for future research.

2. Motivation

2.1. Problem Statement

Traditional sources for PMESII values, such as intelligence data or expert assessments, are often inaccessible due to confidentiality restrictions or exhibit biases based on subjective interpretation. This data gap limits the ability to create unbiased and reproducible initial conditions for simulations.

2.2 Goal

The goal of this study is to develop a reliable, replicable process for generating realistic PMESII values based on openly available data [1]. This approach seeks to improve the accessibility and objectivity of PMESII data for military simulations, ensuring that generated values are both practical and broadly applicable.

3. PMESII Framework

3.1 Definition and Components

The PMESII framework encompasses six components—Political, Military, Economic, Social, Information, and Infrastructure—that collectively assess a nation's stability and capability across various domains [2]. Each component provides essential insights into the factors influencing national and regional security.

3.2 Application in Simulations and Wargames

In wargaming and military simulation, PMESII values serve as both starting criteria and indicators of progress, allowing for dynamic adjustments based on simulated events. By accurately reflecting each PMESII component, simulations can more effectively measure

changes in strategic conditions, assess outcomes, and support training objectives.

4. Methodology

4.1 Data Sources

This study utilizes several publicly accessible databases to populate PMESII components:

World Bank [3]: Provides socioeconomic and demographic data relevant to Economic and Social components.

World Population Review [4]: Offers population and health metrics that enhance the social dimension.

Heritage Foundation [5]: Supplies political and economic freedom indices relevant to Political and Economic components.

Global Firepower [6]: Delivers military strength data that informs the Military component.

SIPRI [7]: Provides defense expenditure and arms data, adding depth to Military and Infrastructure dimensions.

4.2 PMESII Generator

The PMESII-Generator aggregates this information, standardizes it, and assigns preliminary values to each PMESII dimension. To further enhance accuracy, we applied a cross-impact weighting technique [8], which adjusts the relative importance of each component based on interdependence identified by subject matter experts (SMEs) (Figure 1). The resulting model thus balances empirical data with expert-driven adjustments, allowing for nuanced initial conditions that are well-suited for serious wargame applications.

Economy									
x	#	Condition	Yes	No	Value yes	Value ?	Value No		
PMESII starting Value (optimized)	1	Is the country part of a significant free-trading economic organization?	x		2	1	0		
	2	Is the country considered developed?	x		2	1	0		
	3	Is the country member of the G20?	x		1	0.5	0		
	4	If YES, is the country member of the G7?	x		1	0.5	0		
	5	Does the country have a stable currency? (normal average inflation rate < 3% per year)	x		1	0.5	0		
	6	Are sanctions in place?		x	1	0	1		
	7	Is the budget for the military over 2% of the GDP?	x		0	0.5	1		
	8	Economic benefits are distributed equally for the society?		x	2	1	0		
	9	Is the media landscape controlled by government?		x	1	0.5	0		
	10	Does industry have a significant share in the economy?	x		1	0.5	0		
	11		x		0	0	0		
	12		x		0	0	0		
	13		x		0	0	0		
	14		x		0	0	0		
	15		x		0	0	0		
PMESII starting Value:							13		
PMESII starting Value (optimized):							11.11		

Figure 1: PMESII Generator Example for "Economy"

5. Verification and Validation

5.1 Verification Approach

To ensure the accuracy and relevance of the generated PMESII values, a verification process (survey) was conducted involving subject matter experts (SMEs) in military strategy and simulation. Participants included

58 military and civilian experts, ranging from rank OF-5 to OF-8, selected from the NATO Defense College (NDC) Senior Course and the WIN 2024 conference.

5.2 Survey Method

Experts were asked to complete a survey consisting of two primary tasks: assigning PMESII scores on a scale from 0 to 9, indicating the condition of each factor (Figure 2), and completing a cross-impact matrix to rate interdependencies among PMESII components. This cross-impact matrix allowed for a quantitative assessment of the dependencies that enhance simulation realism (Figure 3).

Political	Military	Economic	Social	Information	Infrastruct.

Figure 2: Survey Question 1

	P	M	E	S	I	I
P						
M						
E						
S						
I						
I						

Figure 3: Survey Question 2

5.3 Results

Detailed metrics, such as standard deviation and median values, indicated consistent reliability across the selected data. The examples for "Military" are shown in Figure 4 and Figure 5.

M	
Mean	3.224138
Standard Error	0.18248
Median	3
Mode	4
Standard Deviation	1.389725
Sample Variance	1.931337
Kurtosis	-0.95002
Skewness	0.029269
Range	5
Minimum	1
Maximum	6
Sum	187
Count	58
Confidence Level(95.0%)	0.36541

Figure 4: Statistical Analysis. Example for "Military"

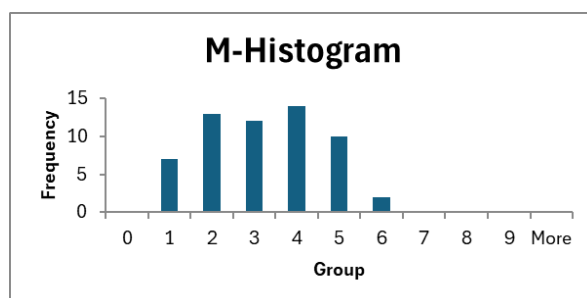


Figure 5: Histogram. Example for "Military"

The verification process yielded valuable data, highlighting both the accuracy and areas for improvement in the PMESII-Generator's output (Figure 6). Statistical analysis of the expert scores (Figure 7) revealed a high degree of alignment between the generated PMESII values and the expert assessments, particularly for the Political, Economic, and Infrastructure dimensions, which achieved mean scores within a 5% variance from the SME evaluations.

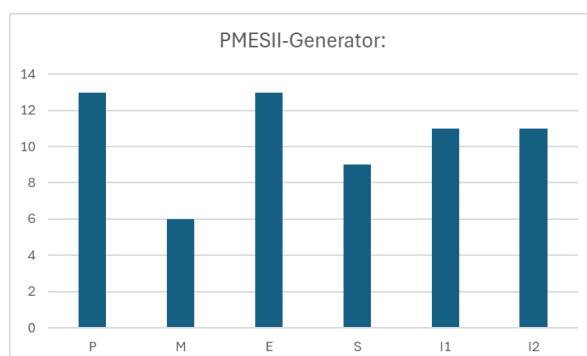


Figure 6: PMESII Generated Values

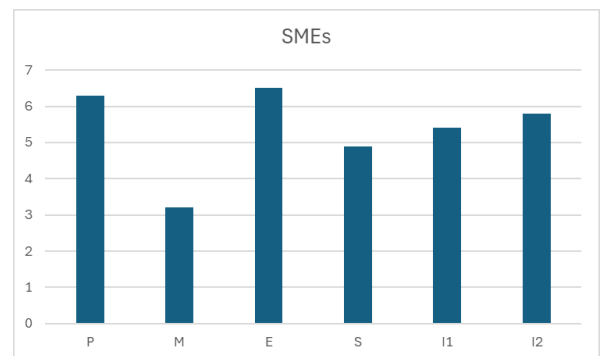


Figure 7: SME Generated Values

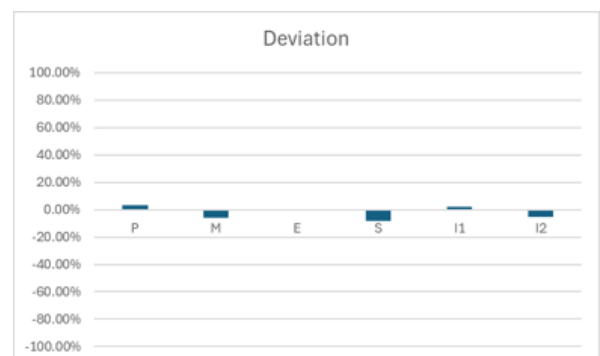


Figure 8: Deviation

Although, slight discrepancies were observed in the Social and Military dimensions, suggesting the need for additional data sources or refined weighting adjustments to enhance precision. In these categories the mean scores are within an 8% variance from the SME evaluation (Figure 8).

Overall, the results confirm that the PMESII-Generator provides a dependable baseline for wargame simulations, accurately reflecting expert evaluations in most cases.

6. Discussion

6.1 Interpretation of Results

Nevertheless, slight discrepancies were observed in the Social and Military dimensions, suggesting the need for additional data sources or refined weighting adjustments to enhance precision. Overall, the results confirm that the PMESII-Generator provides a dependable baseline for wargame simulations, accurately reflecting expert evaluations in most cases.

6.2 Limitations of the Approach

Despite its strengths, the PMESII-Generator has certain limitations, such as the variable timeliness of open-source data and occasional gaps in coverage for specific regions or sectors. These limitations suggest

the need for continuous data updates and refinements to improve regional accuracy.

6.3 Comparison to Alternative Approaches

Compared to traditional methods that rely on classified intelligence or subjective expert input, the PMESII-Generator offers a transparent and scalable alternative. However, while it offers strong baseline accuracy, specific high-stakes simulations may benefit from hybrid approaches combining open-source and classified data.

7. Conclusion

7.1 Summary

This paper presents a validated approach to generating PMESII starting values through open-source data, effectively addressing accessibility and accuracy limitations in military simulation scenarios. The PMESII-Generator offers a reliable alternative for setting baseline conditions across diverse wargame applications.

7.2 Outlook

Future research should explore expanding the PMESII-Generator's database integration, improving regional specificity, and testing the model in varied simulation contexts. Additionally, adaptations to specific military applications, such as humanitarian or peacekeeping simulations, could further broaden its utility.

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Learning From Wargaming And Foresight Methodologies And Practices Applied To Education And Training For Multi-Domain Operations

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Abstract

This article is a description of a Defense University's M&S research projects using wargaming and foresight methodologies and practices applied to education and training to improve multi-domain operations in support of military operations and decision making. The demands for Multi-Domain Operations to provide from humanitarian relief to armed forces engagement come from reactions of the nations to great disasters, wars and conflicts. These are complex phenomena that take place in an uncertain and dynamic environment where human and nations power relations, new and on-going developing technologies and the forces of nature, such as hurricanes and tsunamis, are very powerful and somehow unpredictable. In this sense, we must do our best through modelling and simulation, but because the necessary data, information and knowledge has huge different and interconnected sources, the way it is done can be improved through inter-agency and civil-military cooperation as well as long range vision of alternative futures. This paper investigates the collaborative dynamics, anchored in Brazil's experience, in wargaming and scenarios planning conducted by the Scenarios and Simulations Lab, a sector of the Brazilian Naval War College, as examples of involving civilian and military researchers and practitioners, emphasizing their integral role in bringing out of the box thinking, forward looking perspectives and signs of interest to the Multi-Domain Operations with a focal lens on the Global South perspective. A framework is employed to analyse industry and academia participation, inter-agency cooperation and foresight methodologies and practices. It is innovative to glean comprehensive insights into maritime security dynamics, simulations and scenarios. Here long range and micro scenarios are considered as different plausible future environments that can be imagined, are used not only as an alternative to single line forecasts, but as an intelligent strategic conversation language allied to the

organizational learning process. Agents Joint Assessment and Planning Tool (AJAPT), a fifth-generation software and methodology dedicated to performance analysis within simulations with micro scenarios, facilitates decision-making behaviors among security actors within cooperative inter-agency arrangements, providing invaluable insights into their interactions and strategies, and potentially shaping future policies in the process. Based on an analysis of wargaming, simulations and scenarios, this paper highlights the importance of providing cooperation between various sources of knowledge, alternative futures thinking and a multidisciplinary approach as requirements for improving the contribution of Modelling and Simulation to Multi-Domain Operations.

1. Keywords

Wargaming; Foresight; education and training; Multi-Domain Operations; Scenarios.

2. Introduction

The demands for Multi-Domain Operations to provide from humanitarian relief to armed forces engagement come from reactions of the nations to great disasters, wars and conflicts. These are complex phenomena that take place in an uncertain and dynamic environment where human and nations power relations, new and on-going developing technologies and the forces of nature, such as hurricanes and tsunamis, are very powerful and somehow unpredictable (Lauro & Correa, 2022).

At the beginning of the 19th NATO CA2X2, the keynote speakers used words and ideas of goals to that meeting like: cultural mindset, put people in the process, future thinking, failing fast, networking and interconnection with industry and academia, the real world versus modeling and simulation non realities, be able to do that together, not only multidomain but multinational context, and thus, multi-cultural language and contexts. They can be seen as challenges to modelling and simulation, beyond and through the computer capabilities.

In this sense, we must do our best through modelling and simulation, but because the necessary data, information and knowledge has huge different and interconnected sources, the way to deal with those challenges can be improved through inter-agency and

civil-military cooperation as well as, long range vision of alternative futures.

This paper shows options for many of those challenges when investigates the collaborative dynamics, anchored in Brazil's experience, in wargaming and scenarios planning conducted by the Scenarios and Simulations Lab (a sector of the Brazilian Naval War College) and presents examples of involving civilian and military researchers and practitioners, emphasizing their integral role in bringing out of the box thinking, forward looking perspectives and signs of interest to the Multi-Domain Operations with a focal lens on the Global South perspective.

A framework is employed to analyze industry and academia participation, inter-agency cooperation and foresight methodologies and practices. It is innovative to glean comprehensive insights into maritime security dynamics, simulations and scenarios.

In the annals of military strategy and tactical training, methods of simulating critical periods and war conjunctures have captivated the interest of military institutions at least since the beginning twentieth century. This fascination birthed models within war planning and academic institutions, each aimed at forecasting states' behaviors amidst complex decision-making processes (Low, 1981). Whether rooted in coordinated state actions or tactical maneuvers, the post-World War II era, and the subsequent Cold War, witnessed the evolution of simulation methodologies, striving to rationalize military movements and strategies (Bruvoll et al, 2015; Emery, 2021; Turnitsa, Blais & Tolk, 2022). Today, a diverse array of simulation models finds application in educational and analytical contexts, provoking behavioral conditions, and exploring dynamics within international relations (Evensen et al., 2019; Appleget & Cameron, 2015). Currently, the Model United Nations (MUN), stands as a notable example of fostering a culture of peace and diplomacy amidst shifting geopolitical landscapes with gamification techniques that proved to be efficient in training and knowledge apprehension.

In the realm of strategic planning and decision-making, the utilization of simulations has been a longstanding practice, evolving to meet the complexities of modern environments and learning processes (Alinier & Verjee, 2019; Davis, 2021; Hirst, 2022). One of the initiatives that arisen from the scene was AJAPT, the Agents Joint

Assessment and Planning Tool, representing a fifth-generation software and methodology dedicated to performance analysis within simulations (Medeiros, Mendes & Paiva, 2019). Developed collaboratively and honed through various applications within high-level military and civilian environments, AJAPT helps facilitate the visibility of decision-making behaviors among security actors within cooperative inter-agency arrangements, shedding light on intricate decision-making processes and enhancing collaborative efforts. The historical roots of simulations in strategic planning paved the way for the development of methodologies such as the Performance Analysis Method (Medeiros, Mendes & Paiva, 2019), which spearheaded the AJAPT developments while under development and served as an analysis tool for various political high-level simulations.

3. Thinking out of the box

The U.S Fleet Admiral Nimitz, when returned from World War II, wrote a letter to the president of The US Naval War college, thanking for the wargaming of combat scenarios they have practiced at their war gaming center.

He said: “nothing that happened during the war was a surprise, except the kamikaze tactics; we had not visualized those”. One main reason for they had not visualized the kamikaze tactics is the lack of open minds and open moods in those planning boards and wargames to perceive and to analyze the small signs of the futures, that could come from sources of knowledge such as anthropology or religion, as it was in the kamikaze case (Lauro, Corrêa, & Honório, 2020).

As we all know, for the signs of awareness about the sinking of the HMS Titanic, of the al Qaeda on September 11 attacks, and of the 2020 Pandemic were previously emitted, but ignored.

To catch the signs of awareness we need at least two conditions: open-minded people and methods to keep searching for them; and an internal process flow, based on an open institutional culture to receive and process and deliver the results to the high echelon level.

This paper will present the experiences conducted by the Scenarios and Simulations Lab (LSC), a sector of the Brazilian Naval War College (EGN) where more than 100 researchers and practitioners, 90% civilians,

from different academic backgrounds, 40% Me, 30% PhD, universities and companies contribute mostly on a volunteer basis, emphasizing their integral role in bringing out-of-the-box thinking, forward-looking perspectives.

The researchers and practitioners of the LSC have been, along the last 12 years, understanding “simulations” as stimulating strategic debates useful to refine crisis management protocols at tactical and operational echelons (Medeiros, Mendes & Paiva 2021) and “scenarios” as different plausible future environments, alternative to single line forecasts, that provide an intelligent strategic language and open the mind for the unknowns (Van de Heijden, 2005).

4. Strategic planning with long rang scenarios

Strategic foresight with long range scenarios is mainly qualitative descriptions of the environment in the next years or decades, also based on some quantitative forecasts, as a form of thinking and organizing differently within the contingencies of the present that are used to make decision mindful of the unpredictable future and to enhance the organizational learning process (Corrêa, 2011; Sarpong, Eyres & Batsakis, 2019).

The Scenarios of Defense Research Group of the LSC has a participatory approach related to the mentioned diverse composition and intelligent structure that combines from PhDs to undergraduate personnel, all invited to think and produce about the future of Security and Defense and develop relevant knowledge and insights to refine these fields and inform decision-makers.

Since the last 6 years, they have been working on the following projects related to strategic planning with long rang scenarios:

a) Amazonia Azul Defense Technologies - the project to this the public company was made using a plural methodological arrangement made up of the following futures study tools: literature review; environmental scanning; interviews; survey; futures seed design and validation workshops; Delphi survey (in 2 rounds); cross-impact workshop and calculation; and scenario description., the LSC team developed and fed an

online document for cataloguing, categorizing and storing open source files.

The methodological approach adopted, in line with futures studies literature, was based on defining, treating and prioritizing trends, disruptions and uncertainties. Having selected the 7 most impactful uncertainties for the company, the logic of each of the four scenarios was developed using simulation techniques, with the support of a computer tool, which considered the two most critical uncertainties, obtained through the Delphi survey and the use of the cross-impact matrix to simulate the behavior of the other uncertainties and their most likely combinations in each of the scenarios.

Throughout the process, 70 people were consulted, from different areas of knowledge directly or indirectly linked to the uncertainties raised, as a way of broadening the necessary multiplicity of information sources and approaches to account for the complexity of the interactions between the environment and the system being researched.

- b) Prospective Scenarios for the Brazilian Navy Strategic Planning Cycle 2024-2027 - also made using almost the same methodological arrangement of Amazul, but during 20 months and with a large involvement of sectors and echelons of the Navy and of many different representative personnel of the regions of Brazil, the scenarios were constructed also with a Delphi query involving 517 experts of four groups: 109 Admirals, 63 members of Brazilian Navy Strategic Think Tank, 286 senior officers and representatives of society appointed by them and 59 members of the LSC and the EGN faculty.
- c) Defense Futures Seed Monitoring Network - is a combined project of the Ministry of Education and MoD, with the leadership of the LSC and more than 100 researchers and professionals from 12 institutions as civilian and military colleges, think tank, business enterprises and associations. This project aims to create the model of a collaborative research and monitoring network for seeds of the future environment, supported by computer platform, multi-criteria analysis, with national coverage, public and private, civilian and military

social participation to monitor the MoD's prospective scenarios and dual use (Corrêa, Janick, 2021).

- d) Seeds of the Future in Defense – is a digital bulletin, monthly disseminated via email, LinkedIn, Instagram and Facebook. It's objective is to stimulate and disseminate future thinking on strategic defense and security issues, providing sharp prospective signs to help the Brazilian Defense branches to develop long-term strategies about this themes directly or indirectly related to defense: electromagnetics threats; biodefense and food security; resource scarcity; nuclear and future energy sources; future war; maritime environment; space security; maritime-naval trends and impacts; cybersecurity; artificial intelligence and internet of things.

5. Planning performance analysis with micro scenarios

In the pursuit of refining strategic planning and decision-making processes, the LSC was the first lever for the development of the Performance Analysis Method (PAM). The Performance Analysis Method emerged as a systematic framework for dissecting and evaluating participants' performance within simulated environments. Rooted in qualitative methodologies and informed by real-world insights, this method enables the assessment of individual and collective behaviors, decision-making processes, and interagency collaboration observation (Medeiros, Mendes & Paiva 2021). Planning performance analysis involves the environment design (also called scenario), the consideration of factors impacting group behavior, and the utilization of performance metrics and data collection methods to inform strategic decision-making.

This endeavor unfolded against the backdrop of pressing challenges, including the imperative to enhance the interoperability of the Brazilian Security Forces for major international events such as the 2014 World Cup and the 2016 Olympic Games. Between the years 2012 and 2014, a pivotal partnership between the Brazilian Naval War College and the State Police Academy of Rio de Janeiro culminated in the execution of four simulation editions for the Training Course of Operators in Security of Large Events (COGEST). The overarching objective of these simulations was to bolster the cooperation and

coordination among the country's Security Forces, setting the stage for seamless collaboration during the forthcoming international spectacles. Unlike traditional United Nations simulation models, these exercises were characterized by their multilateral nature imbued with cooperative elements that mirrored the real-world demands of interagency collaboration (Medeiros & Corrêa, 2017).

Central to the design of these simulations was the creation of fictitious yet prospective scenes crafted to encompass the myriad security threats poised to challenge public and national security during major events. Cognizant of the complexities inherent in such endeavors, the design teams strived to foster an environment conducive to the exchange of ideas, crisis management testing, and interinstitutional discourse among security forces, spanning both public and private spheres. At its core, the simulations served as catalysts for stimulating strategic debates and refining crisis management protocols at tactical and operational echelons.

The Performance Analysis method emerged as a pivotal tool within this milieu, offering a systematic framework for dissecting and evaluating the performance of participants within the simulated environment. Employing a blend of observation, data collection, and analytical techniques, the method Performance Analysis enabled stakeholders to glean actionable insights, identify areas for improvement, and inform strategic planning initiatives. Someway, it also encapsulated a concerted effort to harmonize simulation design with methodological rigor, thereby fostering a dynamic and iterative process for enhancing organizational readiness and response capabilities in the face of complex security challenges.

At its core, planning a performance analysis involves a systematic approach aimed at dissecting and evaluating the performance of participants within these simulated environments, once scenarios are attached to expected positions driven by some sort of personal intervention from the actors. The process unfolds in key stages, beginning with the design of the environment in which the simulation will be held. This scene is crafted to address the objectives of the analysis, drawing upon insights from subject matter experts and stakeholders to ensure their accuracy and relevance.

Once the scene is defined, the next step is to identify the factors influencing group behavior, as well as possible outcomes attached to the defined objectives. This includes examining individual behaviors, communication patterns, decision-making processes, and the dynamics of collaboration. As so, analysts can gain insights into the effectiveness of participants' responses and identify areas for improvement once they understand these factors. Thus, with the factors identified, the selection of performance metrics becomes paramount.

These metrics may encompass measures of efficiency, effectiveness, adaptability, and communication effectiveness, tailored to the objectives of the analysis. Methods for data collection are then chosen to capture relevant insights and observations, which may include direct observation, surveys, interviews, and analysis of simulation outputs. The data collected from the simulation is subsequently analyzed and interpreted to extract meaningful insights. Patterns, trends, and critical factors influencing outcomes are identified, offering a deeper understanding of the dynamics at play. These insights inform decision-making processes and strategic planning initiatives, identifying areas for improvement and driving organizational effectiveness.

Planning performance analysis to obtain micro scenarios represents a dynamic and interactive process, aimed at unlocking insights into group behavior and performance within simulated environments. Consequently, analysts can gain actionable insights to inform decision-making processes and enhance organizational effectiveness.

6. Understanding micro scenarios

Micro scenarios are detailed and focused narratives that depict specific situations or events within a broader context and, unlike traditional scenarios which often provide overarching narratives or general outlines, micro scenarios zoom in on aspects, such as specific interactions, decisions, or outcomes (Brauner, 2024). This granularity enables a more nuanced analysis of complex systems and behaviors, as micro scenarios capture the particularities and subtleties that may be overlooked in broader frameworks.

The main argument here posed is that wargaming serves as a crucial methodology for generating micro scenarios, as it provides a structured and interactive

environment for exploring potential outcomes from decision-making processes. Through wargaming exercises, participants engage in simulated ambiances, testing strategies, evaluating consequences, and refining approaches in real time (Appleget & Cameron, 2015). These interactions generate a wealth of data and insights that inform the development of micro scenarios, as the observed behaviors and outcomes serve as the basis for narrative construction.

Micro scenarios can offer relevant advantages for performance analysis, including flexibility, realism, and collective behavior insights, as they enable targeted assessments of specific decisions or interactions, fostering a deeper understanding of group dynamics. The granularity of micro scenarios may allow researchers to focus on particular aspects or variables of interest, unrestricted by broader frameworks. By depicting detailed scenarios, simulations can provide a more accurate representation of complex systems and environments, thereby enhancing the relevance of performance analysis, which is based on combined rational-emotional decisions (Perla & McGrady, 2011). Once behaviors cannot be absorbed due to bounded rationality within the whole process, micro scenarios can facilitate the identification of patterns, trends, and critical factors influencing outcomes, empowering stakeholders to gain actionable insights and effectively inform decision-making processes (Schatzmann, Schäfer & Eichelbaum, 2013).

Another aspect to be cited is that micro scenarios can offer a nuanced approach to scenario planning, focusing on detailed and specific situations rather than overarching narratives, with a straight and shorter view of the future (Schatzmann, Schäfer & Eichelbaum, 2013). Generated through wargaming processes, micro scenarios differ from traditional scenarios by their specificity, enabling analysis to obtain a deeper understanding of complex interactions and decision-making dynamics. Using micro scenarios through performance analysis can also boost simulations whilst allowing for targeted assessments of group behavior, feasibility, and strategic implications.

In the realm of strategic planning and decision-making, the process of planning performance analysis based on micro scenarios is a crucial endeavor. Detailed and focused narratives depicting specific situations within a broader context serve as the foundation for this analysis, providing the framework for targeted

assessments of individual actors and group behaviors within less visible futures.

7. Driving feasibility assessment and gaining visibility into future scenarios

Feasibility assessment within the context of building micro scenarios entails evaluating the viability and practicality of different scenarios based on predefined criteria. Criteria may include resource availability, technological feasibility, actors/stakeholders alignment, and risk mitigation strategies. The importance of feasibility assessment cannot be overstated, as it forms the foundation for informed decision-making and strategic planning, ensuring that proposed actions are realistic and achievable.

Micro scenarios offer a lens into possible future scenes, providing insights into emerging trends, challenges, and opportunities, where the analysis and interpretation of micro scenarios enable organizations to anticipate and prepare for potential developments, enhancing strategic foresight and resilience. By incorporating diverse perspectives and leveraging collaborative approaches, micro scenarios empower organizations to navigate uncertainty and adapt to evolving circumstances.

In the realm of strategic planning, feasibility assessment within the context of micro scenarios serves as a vital component because it involves the exploration of potential scenarios and evaluating their practicality and viability within the given context. This assessment seeks to determine whether the proposed scenarios align with organizational goals, resources, and constraints. By conducting feasibility assessments, decision-makers can identify feasible pathways forward, mitigating risks and maximizing opportunities for success.

When evaluating the feasibility of different scenarios, several criteria come into play. These criteria encompass various aspects, including resource availability, technological feasibility, market demand, regulatory compliance, and organizational capacity. Each scenario is scrutinized against these criteria, weighing the potential benefits and challenges associated with its implementation. Through this process, decision-makers can discern which scenarios are most likely to yield favorable outcomes and align with strategic objectives.

Feasibility holds paramount importance in decision-making and planning processes. It serves as a critical lens through which to assess the viability and sustainability of proposed strategies and initiatives. Ensuring that selected courses of action are feasible, decision-makers can enhance the likelihood of achieving desired outcomes and avoiding costly missteps. On the other side, feasibility assessments also empower organizations to allocate resources effectively, optimize performance, and adapt to changing circumstances with agility and foresight.

Micro scenarios offer a unique vantage point for gaining visibility into possible future scenes. These detailed narratives envision specific situations or events within broader contexts, allowing decision-makers to explore potential outcomes and implications. Through analysis and interpretation, micro scenarios illuminate emerging trends, uncertainties, and opportunities, enabling organizations to anticipate and prepare for future challenges, once insights gleaned from micro simulations can inform strategic planning by identifying strategic priorities, guiding resource allocation, and informing decision-making strategies (Whitehurst, 2002; Perla & McGrady, 2011).

In this sense, the AJAPT and associated methods may represent a transformative asset in the realm of building micro scenarios. By integrating expert judgment into the analysis process, it can promote building micro scenarios that are grounded in informed perspectives and insights. Experts with deep knowledge in their respective fields contribute to generating future images and evaluating their likelihood or desirability, enriching the robustness of the scenarios. Within the AJAPT framework, future images undergo evaluation for validity and relevance, where the process refines and selects the most plausible or desirable scenarios, ensuring that micro scenarios are based on robust criteria and considerations.

The method emphasizes participation and interaction throughout the analysis process, driven by the integration of sociocultural and technological dynamics that ensure that micro scenarios are built sensitive to the complexities and uncertainties of the broader environment.

Moreover, AJAPT facilitates a collaborative approach to foresight processes, involving multiple stakeholders and experts early in the process (Medeiros, Mendes & Paiva, 2021; Medeiros, Mendes & Paiva, 2023). This

inclusivity promotes diversity of perspectives, enriching micro scenarios by considering a wider range of possibilities and implications. The system also embraces transdisciplinary and goal-state flexibility, allowing for the exploration of diverse perspectives and adaptation to changing circumstances and, in addition to expert judgment, AJAPT can integrate quantitative data and analytics such as semantic analysis (Medeiros, Mendes & Paiva 2023).

Incorporating insights from data-driven models enriched with empirical evidence enhances possible predictive conditioners. Furthermore, the framework supports continuous improvement and adaptation, allowing for the flexible adjustment of goals and methodologies. This iterative approach permits micro scenarios to remain relevant to guiding decision-making processes over time. Furthermore, it encourages open innovation and knowledge sharing by leveraging collaboration and communication tools, and by sharing future-oriented knowledge.

8. Conclusion

We live in an era of significant dynamics and complexities of the environment, where traditional tools for anticipating the future from the short to the long term are ineffective when we assume that the factors that affect the forecasted phenomenon are constant and don't have reciprocal influence in one another.

Long range scenarios have been used, as a mainly qualitative approach, as a strategic language to describe how possible futures can be shaped and are very useful to improve organizational learning processes, due to their ability to prepare decision-makers to a game of uncertainties, trends and disruption in the next decades.

The participatory approach of the LSC, where hundreds with large involvement of different persons from many Navy sectors and echelons as well as many representative groups are consulted, with national coverage, public and private, civilian and military social participation shows that is very important to Security and Defense area because it brings the opportunity to discuss new out of the box relevant insights about unknown data, information and knowledge to build and monitor the defense prospective scenarios and open new point of view to the decision board.

The mentioned projects related to strategic planning with long rang scenarios, Amazonia Azul Defense Technologies, Prospective Scenarios for the Brazilian Navy Strategic Planning Cycle 2024-2027, Defense Futures Seed Monitoring Network, and Seeds of the Future in Defense present scenarios constructed by a variety of futures study tools that, with the support of a computer tool, collect, measure the cross-impact and prioritize trends, disruptions and uncertainties and it's most likely combinations to build each of the scenarios.

They also provide seeds of the futures in uncommon fields as food security; resource scarcity and electromagnetics threats, as prospective signs to help the Brazilian Defense branches to develop long-term strategies.

Micro scenarios derived from wargaming may be offered from performance analysis and for the benefit of strategic planning. The Performance Analysis method embedded in AJAPT as well as other equivalent simulation tools, can facilitate targeted assessments of group behavior, feasibility, and possible future scenarios, once organizations can gain insights into complex dynamics.

The article discusses the significance of micro scenarios in performance analysis and feasibility assessment, highlighting their specific nature compared to traditional scenarios. It underscores the importance of utilizing micro scenarios from the understanding of group behavior, through its feasibility and strategic implications, as they enable targeted assessments and offer insights that might be overlooked in broader frameworks. The value of gaining visibility into future scenarios is emphasized, as micro scenarios provide a nuanced approach enabling organizations to anticipate trends and prepare for emerging challenges.

At its core, AJAPT facilitates decision-making behaviors among security actors within cooperative inter-agency arrangements, providing invaluable insights into their interactions and strategies. Leveraging case studies and simulations involving state officials, AJAPT permits analysts to delve into the intricacies of inter-agency decision-making processes, with a focus on enhancing collaborative efforts and fostering learning initiatives. These endeavors ultimately pave the way for the development and

dissemination of best practices, potentially shaping future policies in the process.

The integration of AJAPT enhances the process by integrating expert judgment, evaluating future images, fostering collaboration, and incorporating quantitative data and predictive analytics. Ultimately, micro scenarios may empower organizations to make more informed decisions and enhance strategic preparedness in an ever-evolving world.

The next steps are driven by empirically testing and provoking processes that can uphold the previous insights.

In conclusion, in a world in fast change and interconnections, ruled by people and organizations full of hierarchy, vanity and rigidity, as we imagine and understand complex participation, we can better plan Multi-Domain Operations to profit the most from the opportunities and to mitigate and overcome the difficulties and crises. And based on an analysis of the experiences of wargaming, simulations and scenarios, it is important to highlight cooperation between various sources of knowledge, alternative futures thinking and a multidisciplinary approach as requirements for improving the contribution of Modelling and Simulation to Multi-Domain Operations.

9. AJAPT Interface Shots

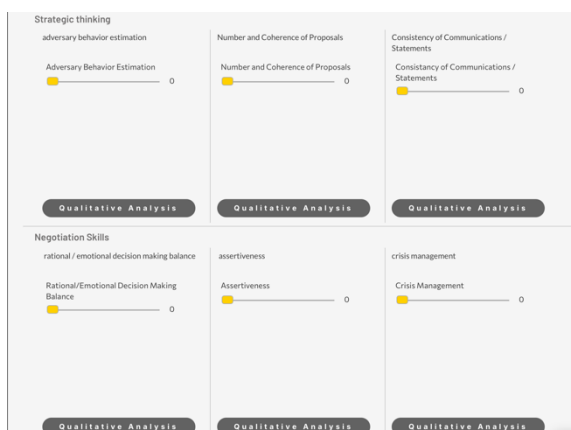


Figure 1 Control Group Communications Interface

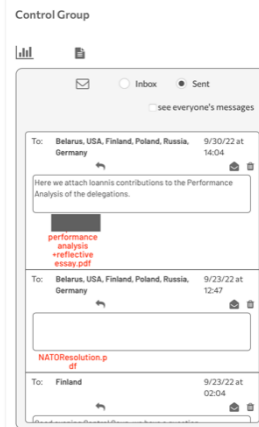


Figure 2 Experts Assessment Interface

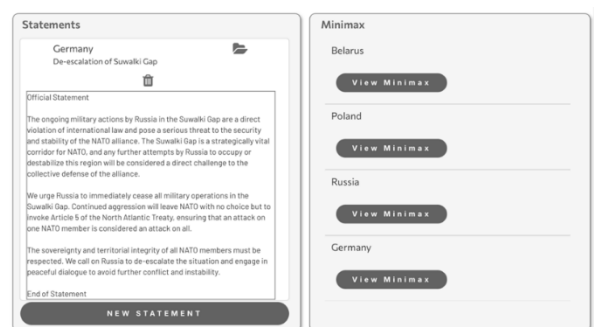


Figure 3 Delegations (Actors) Statements and Strategic Documents

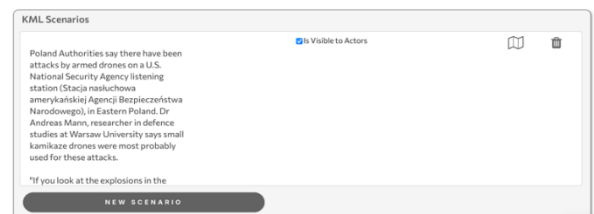


Figure 4 KML Scenarios

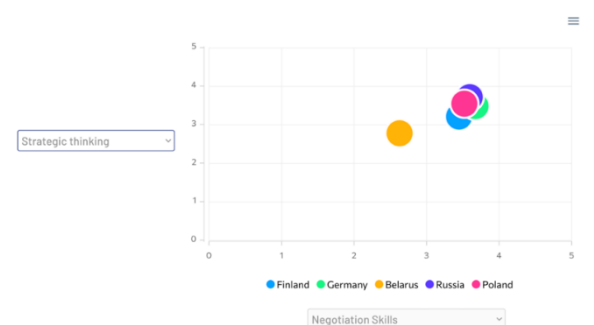


Figure 5 Performance Analysis according to Assessment from the Designer

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Strategic Engineering To Support Decision Makers In Complex Systems: Innovative Models For Cognitive Warfare Simulation

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Abstract

The proposed Solution DRYAS4 (Dynamic Reactive solution for opponent Yielding based on Artificial intelligent Systems, Simulation and Strategic engineering for Success) by Simulation Team, uses Modeling & Simulation (M&S), Artificial Intelligence (AI) and Data Analytics, leveraging the Strategic Engineering approach to support Decision Making in a comprehensive PMESII-PT (Political, Military, Economic, Social, Information, Infrastructure, Physical environment, and Time) Scenario and evaluating the Impacts of DIMEFIL (Diplomatic, Intelligence, Military, Economic, Financial, Information, Law Enforcement) Actions.

DRYAS4 goal is to Simulate, Analyze and support Strategic Decisions respect Global Scenarios including several Nations and their respective Populations, Capitals and Coalitions by a multi-dimensional approach capable of addressing the Physical, Virtual and Cognitive Dimensions, as well as Multi Domain military initiatives.

1. Keywords

Modeling & Simulation; PMESII-PT, DIMEFIL

2. Introduction

The Simulation Team proposes an innovative approach to PMESII-PT (Political, Military, Economic, Social, Information, Infrastructure, Physical environment, and Time) Scenario by creating an advanced Solution using Strategic Engineering Approach and Simulation in order to evaluate quantitatively the Impacts of DIMEFIL (Diplomatic, Intelligence, Military, Economic,

Financial, Information, Law Enforcement) Actions and estimate risks and future consequences of Actions.

3. State of the Art

The integration of Modeling & Simulation (M&S) and Artificial Intelligence (AI) into Strategic Decision Making has evolved significantly, driven by recent advancements and interdisciplinary research. Hybrid simulation techniques, which combine discrete-event and agent-based models, are increasingly utilized to address complex systems, offering robust frameworks for analyzing dynamic environments (Bruzzone et al., 2015; Onggo & Karpas, 2021; Brailsford et al., 2019). Similarly, AI's application in different domains, including generation of content and Operational Management, has highlighted its disruptive potential, especially in automation and Enhanced Decision-Making capabilities (Bruzzone et al., 2023; Kietzmann et al., 2018; Zhou, 2021).

In the Defense sector and for Theater Analysis, Simulation's role is on the rise. Recent studies have showcased its efficacy in enhancing Situational Awareness and supporting joint Operational Planning through realistic Wargaming scenarios (Tremblay et al., 2019; Lee & Kim, 2020). This could be improved even further by applying the Strategic Engineering approach, where data analytics, M&S and AI are combined in a closed loop to improve Decision Making performance and address uncertainty in multi-criteria decision contexts (Wamba et al., 2017; Durbach & Stewart, 2019). Moreover, the PMESII-PT and DIMEFIL frameworks provide comprehensive methodologies for evaluating Operational Environments and Strategic Actions. Their application in Hybrid Warfare and counterinsurgency operations underscores their importance in Modern Military Strategy (Bruzzone et al., 2013; Gomez & Jansen, 2021; Dewey, 2020). As global crises become more unpredictable, these frameworks, supported by advanced M&S and AI, offer critical tools for Decision Makers to navigate complex geopolitical landscapes and identify Effective Strategies. This synthesis of technologies and frameworks marks a progressive shift towards more resilient and adaptive Strategic Decision-Making processes in both military and civilian sectors.

4. Modeling Countries and Layers

Complex Scenarios are related to Multi Dimension interactions over Regions, Countries, Populations and also comprehend critical elements of the PMESII-PT

paradigm, including Cognitive Warfare, Hybrid Warfare, Politics & Strategic Decision Making, Infrastructures, Economic & Industrial Development, Physical and Social Dynamics, Law Enforcement & Crime Dynamics, Civil Disorders, Coalition Operations and Military Strategies. This mix requires new approaches for Modeling able to deal with Comprehensive Simulation and should rely on the use of AI (Artificial Intelligence) Modules, Intelligent.

Agents (IA) and MS2G (Modeling, interoperable Simulation & Serious Games) Solutions, coupled with very advanced HBM (Human Behavior Models) and Decision Support systems. Indeed, DRYAS4 Simulator uses Intelligent Agents (IA), defined as REBIA (Reactive and Emergent Behaviors by Intelligent Agents), specifically developed by SIM4Future various applications, such as to Model the Enemies, Antagonists or Neutral Countries or Entities, as well as to direct Actions coordinated among Allies and Blue Forces. These Intelligent Agents are used to assign to each Nation a standard behavior (such as: Industrial Development, Agricultural Development, ICT Development, Reconstruction, Consensus Focused, Energy Focused, Food Focused, Arm Race, Aggressive Attitude, Defensive Attitude, Local Dominance, Global Dominance) that can enable specific actions to be carried out by the related Entity (such as Hybrid Warfare, Cyber Warfare, Cognitive Warfare, Global Warfare). This innovative approach enables to reproduce Complex System with several entities Acting and reacting to.

Scenario Evolution based on their Goals and their Perception. Thus, the multi-layer Simulation used by DRYAS4 and the use of the REB-Intelligent Agents with Human Behavior Models allows to reproduce the dynamics of Objects and Players over the different complex aspects (e.g. Finance, Economy, National Networks, etc.) respect other Parties and following each Entity's specific goal.

The General Scheme of DRYAS4, reported below, is based on a modular structure and an Interoperable approach to grant the necessary flexibility to integrate different Metamodels for simulating the characteristic aspects of the Scenario from the Population and Demographics of each Nation to the Human Behavior of people and military Personnel, leading to a satisfying Solution for PM-ADM.

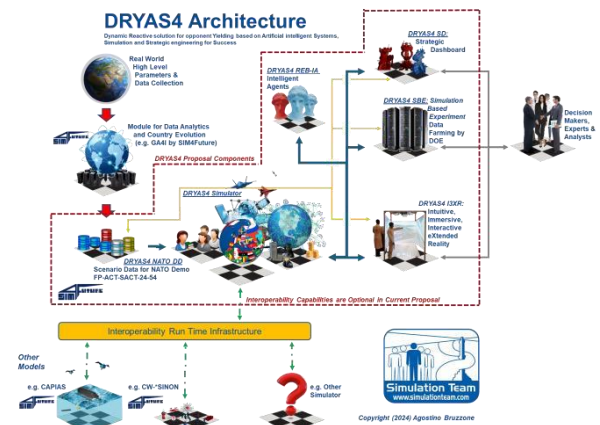


Figure 1 – DRYAS4 General Architecture

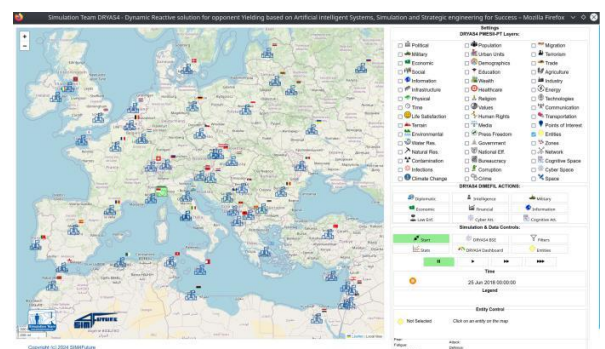


Figure 2 – DRYAS4 Simulator on a proposed Scenario focused on Europe and North Africa and Middle East

DRYAS4 is an Agent Driven Stochastic Simulation that addresses a Comprehensive PMESII-PT Scenario at Theater Level Simulation among Nations. It models the multiple dimensions and layers as networks of Objects based on geo-referred Nodes and Links that are characterized by initial and boundary conditions defining their state, variables, dynamics and statistical behaviors. In order to model the Scenario map and Simulation, each Nation and Entity, such as Coalition, International Organizations or Terror Groups, has been represented as a Node, with linked attributes that constitute the corresponding unique characteristics across the PMESII-PT dimensions, such as political stability, military strength, economic growth, social cohesion, security levels and infrastructure quality. These nodes are interconnected with links that represent the relationships and interactions between each other, specifically in the form of DIMEFIL Actions like trade agreements, military campaigns, diplomatic treaties, people and information flows and each link is weighted to reflect the strength and importance of these interactions. By incorporating stochastic elements, such as random events or shifts in alliances, the Model simulates

dynamic changes and emergent behaviors over time, like the constitution of Alliances or Coalitions among Nations for a common Objective, like Collective Security.

Node Structures on the General Models

Every Node representing a specific Simulation Entity is composed of two distinct elements, a set of HBM elements that are used to model the group and individual behaviors of the Population and a Nation-wide repository that contains and updates the parameters related to the whole entity like its GDP or Military Strength. When each entity is instantiated, the necessary information is drawn from the relative Data Base and an initial Population is sampled from the Nation Demographics.

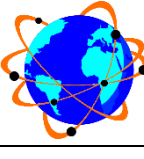
Link Structures on the General Models

Every Link represents an interaction between two or more different Entities or with the Environment. For example, Migration, Military Actions, Cognitive Campaigns and Diplomatic relationships are constituted by links between Nodes that contain all the relevant information, parameters and mathematical functions that are relevant to shape and represent over time the specific Action or Flow considered. The resulting map provides a comprehensive visual and analytical tool for understanding and predicting the outcomes of various International Interactions and policies. DRYAS4 objects are characterized by internal values including among the others:

PMESII-PT LAYERS	
	Political It represents the level of Political stability of a Node considering various aspects like Government, National Efficiency, Terrorism and people Satisfaction
	Military It represents the total Military power of a Node considering its active military units and its capability of sustain and resupply them

	Economics Modelling the Economy Developments
	Infrastructure It represents the level of Physical Infrastructure a Node possesses, such as ports, roads, railways
	Physical The Dimension of Operations
	Life Satisfaction It represents the level of Life Satisfaction of the population of a Node
	Water Resources It represents the Water sheds and resources present in a Node, especially in term of drinkable water to sustain its population needs
	Natural Resources It represents the Natural Resources present in a Node that can be exploited to boost its Industrial capabilities or be traded with other Nodes
	Population It represents the number of people in a Node and its evolution over time
	Demographics It shows the relevant information of a Node population
	Education It represents the general level of Education in the population of a Node
	Wealth It represents the GDP of a Node

	Healthcare It represents the general level of Healthcare in a Node, in terms of expenditure and efficiency
	Cyber Space It comprehends all the critical elements of a Node that can be subjected to a cyber-attack, such as energy supply or communication networks
	Satellites & Outer Space Capabilities It represents the Node Satellites and Space Capabilities, in terms of communication and observation capabilities

DIMEFIL ACTIONS	
	Diplomatic It comprehends all the Diplomatic actions that Nations can take such as negotiations and peace talks, diplomatic sanctions or incentives, treaty formations, alliances and Coalitions
	Information It comprehends all the Information actions that Nations can take such as propaganda campaigns, cybersecurity measures, intelligence gathering and dissemination
	Military It comprehends all the Military actions that Nations can take such as deployment of troops, military exercises and maneuvers, strategic strikes and defense operations

	Economics It comprehends all the Economic actions that Nations can take such as trade embargoes or agreements, economic sanctions, financial aid and investments
	Financial It comprehends all the financial actions that Nations can take such as freezing or seizing assets, financial regulations and policies, currency manipulation
	Intelligence It comprehends all the Intelligence actions that Nations can take such as espionage and counterespionage activities, surveillance operations, data analysis and threat assessment
	Law Enforcement It comprehends all the Law Enforcement actions that Nations can take such as maintaining law and order, protecting citizens and disrupting criminal networks or terrorist organization
	Cognitive Attacks It comprehends all the Cognitive Attacks that Nations can launch such as disinformation campaigns, propaganda messages, delegitimizing actions

5. Conclusions

The proposed Solution is a very innovative Comprehensive Simulation covering PMSEII-PT considering impacts of DIMEFIL by using Simulation in global scenarios. This framework allows for the exploration of Complex Geopolitical Scenarios, assessing how different Strategies or events impact the overall System and individual Nations within the Simulation Environment. The results underscore the importance of simulation as a strategic tool for decision-makers integrated within a Strategic Engineering Approach to understand the dynamics of

complex warfare and guide to right and successful decisions.

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Quantum And 6G Technologies Evolution In The Future Of Warfare And Radar Development

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Abstract

Next generation 6G and "Quantum technologies represent a revolution in military operations that will change in the future the way of operations, from cybersecurity to communications in tactics, operational and warfare strategies in modelling & simulation. Quantum technologies are dual-use technologies, and therefore are of interest to the defence and cyber security industry and military. The recent RADAR systems and the 5G and 6G antennas have contiguous or even overlapping operating principles that allow the development of solutions in a dual use perspective. The convergence between radar and telecommunications can be glimpsed in the use of electronically scanned antennas that for 5G and 6G transmissions use "smart antennas" MIMO - Multiple Input Multiple Output. In the future, we begin to glimpse the evolution towards quantum radar while the "quantum" revolution in 6G with cognitive radio will be the next generation architecture thanks to quantum computers that already allow in 5G the optimal cellular planning of frequencies and transmission network. We are now working on the fusion of technologies with Quantum Machine Learning for 6G networks.

1. Possible use of 5G radio technologies in the evolution of radars

We can see a possible use of 5G radio telecommunications technologies in the evolution of surveillance radars thanks to lower costs and safety in urban environments and in rural operational theaters with 5G network coverage. Today we are witnessing scenarios in which conflicts develop in areas served by radio coverage with high reliability and resilience to cyber-attacks thanks to the protection "by design" of the 5G radio infrastructure. Both of these technological fields use electronically scanned antennas, also known as phased arrays, which allow the

radio wave beam to be directed without the need to physically move the antenna. MIMO (Multiple Input Multiple Output) antennas are a further development in this direction and represent a key component for 5G and 6G telecommunications networks. These smart antennas can transmit and receive multiple data streams simultaneously on a single communication channel, improving channel capacity and signal quality.

Massive MIMO technology, combined with the beamforming techniques enabled by electronically scanned antennas, makes it possible to optimize the use of the radio spectrum and increase the efficiency of communications, while reducing interference. These technological advances not only improve the performance of telecommunications networks but can also be applied for military and civilian purposes, highlighting the dual use potential of such technologies. In particular, the use of beamforming and MIMO techniques can be employed to create more advanced radar systems, with better object detection and tracking capabilities. At the same time, 5G and 6G networks can benefit from innovations from the radar sector to improve the capacity and reliability of wireless communications.

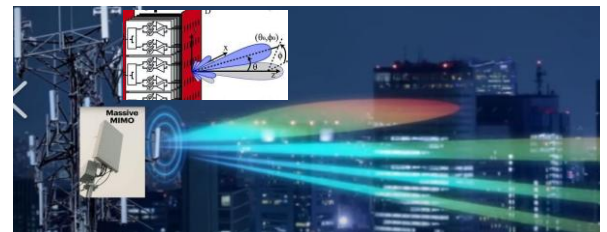


Figure 1: 5G Antenna and radar: Massive MIMO and Beam Forming

2. The quantum evolution of radar

In the future we are starting to glimpse the evolution towards quantum radar while the "quantum" revolution in 6G and the introduction of Cognitive Radio will be possible thanks to quantum computers which already allow optimal planning of frequencies and cellular coverage in 5G.

Artificial intelligence will be both local and distributed thanks to fog computing architectures and quantum computing capabilities. At the following link you can read an in-depth analysis on 6G: <https://www.agendadigitale.eu/infrastrutture/verso-il-6g-models-and-strategies-for-the-Italian-andEU-ecosystem/>

In fact, we are working on the fusion of technologies with Quantum Machine Learning for 6G networks: the state of the art in research is available in the article IEEE Quantum Machine Learning for 6G Communication Networks: <https://ieeexplore.ieee.org/document/8681450>

Quantum communications also affect radar systems. Quantum radar is a device that uses "entangled photons", that is inextricably linked to each other. Experimental versions are being implemented. The quantum radar is currently in the prototype phase or in a very early experimental phase and is based on the principle of quantum entanglement based on remote quantum correlations which allow the target detection sensitivity to be increased. However, the creation of a working quantum radar prototype is not yet on the horizon but is at the center of interest in some countries.

3. Global Quantum Warfare: a rapidly evolving and growing market

The global quantum warfare market size had a revenue of around USD 136 million in 2022. A rapidly developing market that is expected to grow to USD 528.7 million by 2030 with a compound annual growth rate (CAGR) of approximately 18.5% between 2023 and 2030. Source Quantum Warfare Market Size, Share, Demand, Trends, Growth 2023-2030 ([zionmarketresearch.com](https://www.zionmarketresearch.com))

Quantum Warfare (QW) is a domain for new defense scenarios in which quantum technology is used for strategic military objectives and requires new employment doctrines.

NSA fears quantum computing surprise: "If this black swan event were to happen, then we are really screwed." Intelligence fears China and other adversaries may make breakthroughs in key technology.

NSA fears quantum surprise: 'If this black swan event happens, then we're really screwed' - Washington Times

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