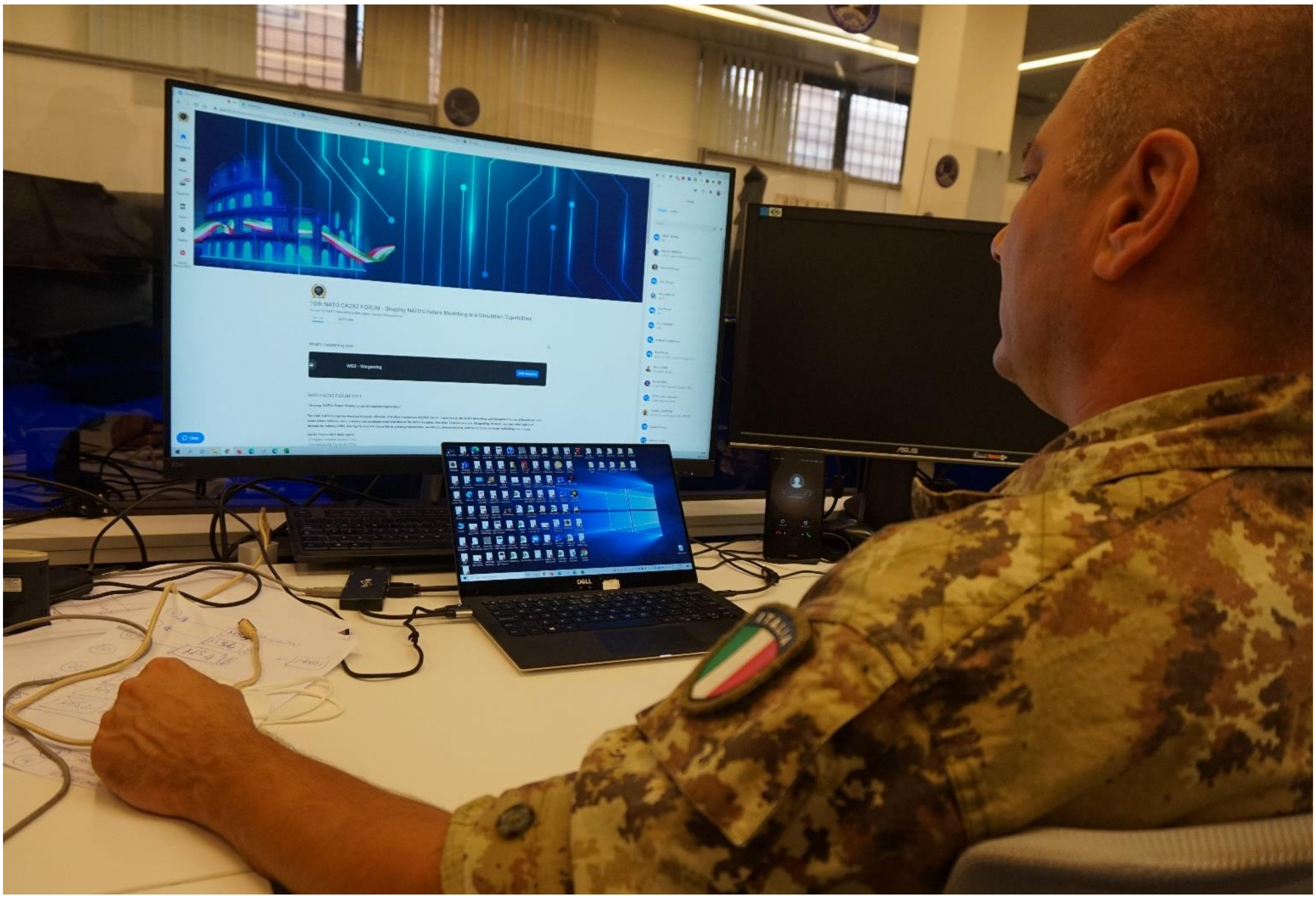
Part 2:

CA²X² Forum 2021



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The CA^{2}X^2 Forum 2021

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Stefano LO STORTO
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NATO M&S CoE DIRECTOR

This book contains the proceedings of NATO M&S CoE's Computer Aided Analysis, Exercise, Experimentation annual conference held, online from 4-8 October 2021.

The principal theme for the conference was:

'Modelling and Simulation Enabling NATO and Nations'

Through a 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

5G, the fast network for the battlefield: digital transformation overview

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Abstract

Next generation 5G wireless technologies represent a revolution in military operations that will change the way of operations, from training to logistics to the tactics, operational and strategic of warfare.

Drones have already entered best practice for battle theater operations and can be used for both coastal research and military base camp security. Currently, drones function simply as an additional "eye" in military operations, but they will soon have a "brain" based on artificial intelligence (AI) and big data, and will be able to operate undercover autonomous driving. 5G. It will be presentede a simulation & modelling concept.

Use case : 5G enables new solutions for high-risk civilian and military activities and operations such as the removal of anti-personnel mines or explosives. For example, 5G allows unmanned operation of excavators for the removal of anti-personnel mines. In fact, it instantly provides high-resolution video and thanks to the very low latency of a few milliseconds, it allows you to operate remotely in real time with the tactile internet.

1 Introduction

The Telecommunication industry is playing a crucial role in enabling this digital transformation that is affecting all vertical markets (Finance, Automotive, Public Sector, Healthcare ...).

The increasing availability of technological platforms in a perspective of convergence between Mobile, Artificial Intelligence, Cloud, Big Data / Analytics is dramatically changing the way we live, work, and interact. This trend is part of the Fourth Industrial Revolution, called "Industry 4.0".

Telecom operators' share of the industry profits show a constant decrease in revenues, despite their fundamental role in enabling digital transformation in all industries and public sector

The new investment and business opportunity scenarios for ICT enterprise, professionals and engineers are linked to the development of LTE and 5G technologies in the mobile and in the fiber infrastructure and Cloud with the emergence of Software Defined Network architectures in networks whose security and resilience are at the centre of the Investments. The new business models respond to the growing market demand for "ultra-broadband-enabled mobile data applications" which are central to the vertical markets of Industry Finance, Tourism, Public Sector, Automotive, Energy, PA-Defence. Industry 4.0 is at the centre of the "digital Transformation" of Telecommunications and benefits from the new 5G network architectures envisaged in the 5G operators development programs The telecommunications industry has provided all the building blocks of the infrastructures: fixed and mobile broadband access network, core infrastructure, interconnection and cloud application platforms.

2 Digital Transformation & Telco Industry for dual use military applications

The whole process of digital transformation will depend on the Telecommunication Industry which is enabling changes also in the organization of work as in the case of smart working. Operators tend to differentiate themselves both in business models and in the services offered to Business and Consumer customers. However, despite the role played by the Telecommunication Industry is fundamental in the acceleration of the digital transformation in business processes, we do not find a similar advantage with a significant confirmation in the increase in value for the Telco operators that have contributed to this development. This despite new investments in networks and infrastructure innovation. The closer the performances of the Telco operators are, thanks to better performing networks, the more difficult it is to stand out, thus leading the industry to search for new business models and meet customer needs through innovation. An explosion of services, however, that does not generate an equally significant growth in benefits for telecommunications operators caused by the migration of revenues from Telco operators to Over the Top. We are thus witnessing rapidly changing business models, a paradigm leap in technology with IP and SDN infrastructures, and the convergence of Cloud, Mobile, Social and Big Data platforms. Everything is changing in the telecommunications industry with unprecedented acceleration that is taking shape with 5G.-

5G business models meet a growing market demand for ultra- broadband-enabled data applications within vertical market segments including Finance, Tourism, Public transportation, Energy and Defence. Furthermore, enterprise mobile applications will receive benefit from lower latency and improved spectrum efficiency (i.e. Software Defined Radio and Cognitive Radio in a increasing overall network capacity). Delay and latency are fundamental to developing new services in 5G market: 5G is not only an evolution of the current 4G - LTE but it is presented as a paradigm leap that will lead to the opening of new scenarios and to the development of services and business models in vertical markets.

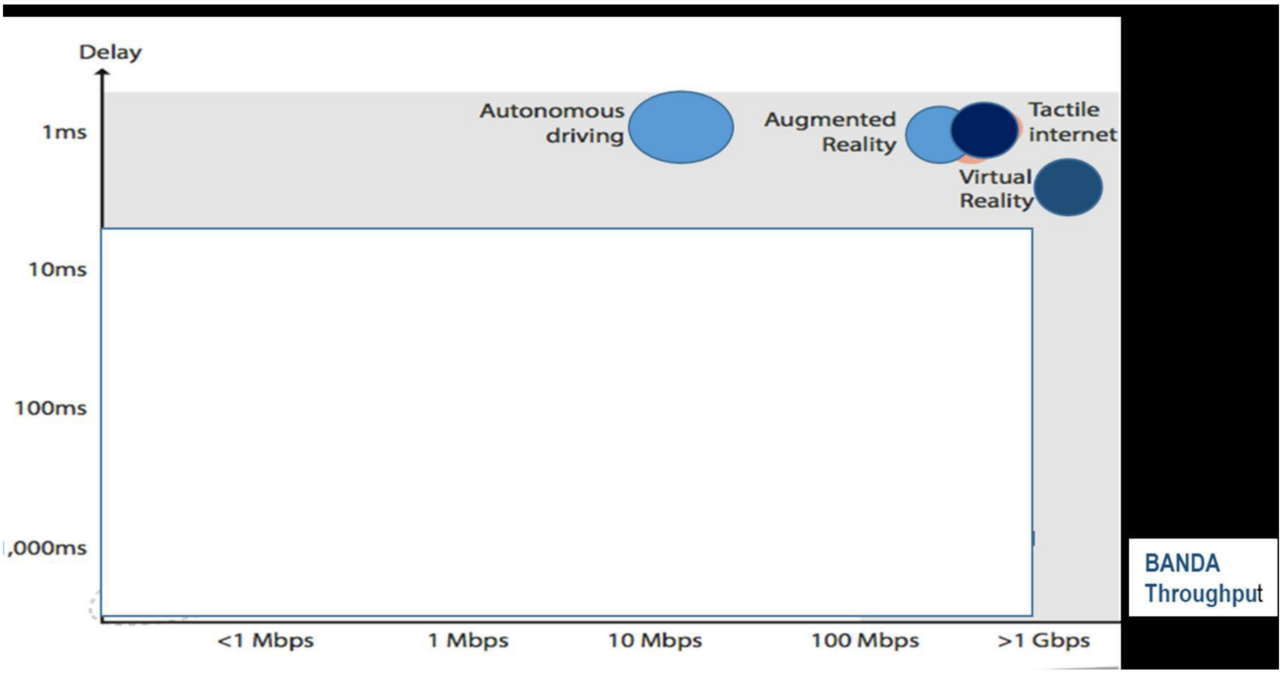

Figure 1 – Delay vs Throughput in 5G services

The new 5G mobile network will increase connection speeds by integrating more access modes, far superior to 4G, and will guarantee very low latency times, and in consideration of high performance will enable the connection of wireless devices and sensors in the architecture IOT. The 5G network is designed for the new cyber security scenarios by offering resilience and mitigating attempts to violate the mobile telecommunications infrastructure. With these characteristics, 5G will lead to the creation of services that will change the way people live, produce, work and move. For these reasons, the advent of 5G is an integral part of the Fourth Industrial Revolution, Smart land circumstances.

Figure 2

Tools and methodologies for dual use applications modelling will be presented, in order to be aware about this research area.

Figure 3

A fundamental issue is to think long-term scenarios and to provide true market projections for the 5G next generation wave. To this purpose, specific tools and business models with a particular stress on the economics and revenues drivers have been developed in the best practice The use of simulators will facilitate the understanding of the initial situation and its possible evolutions, as well the identification of the future economical potentialities.

The purpose of this simulation model is to construct a system that can provide with preliminary evaluation for a range of major scenarios in dual use military applications. The model is able to provide market forecasts for a range of wireless telecommunication businesses including 5G, existing wireless as well as new opportunities to form part of the overall business plan. The business model tool provides good results based on the input information. However, high quality and reliable results will require intervention from a skilled analyst to input and interpret other factors such as likely competitive environment - therefore the user will need to be highly skilled in understanding telecommunications markets.

Today big players in 5G emerging military applications are defining strategic priorities and simulations models

We need to reinvent 5G business model in a Cloud Centric Network Sharing Platform, furthermore we need to imagine the role of the Wireless Service Provider of the Future.

Key words are ICT Cloud centric network sharing platforms and Internet of Things

Use cases need to be described in vertical markets: smart mobility / connected military vehicles. We envisage a new market push in 5G due to Telco infrastructure enhancements to broaden the opportunity for IoT and M2M applications.

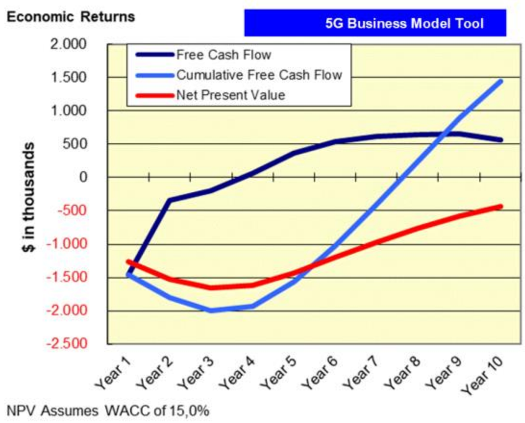

Figure 4:

3 ICT trends and 5G: Maintaining the promise

The digital transformation in vertical markets and public sector shows that these interdependent trends are "transforming the way people and businesses relate to technology"

The Industry 4.0 transformation process must however be placed as a piece of the more general process of technological change that will affect, sector by sector, all segments of the economy: from Public Administration to energy industry, from tourism to pharmaceuticals. A process of transformation that will be characterized by an important process of technological deflation, inevitably connected to the progressive dematerialisation of production processes and products. Business models are key to understand future market developments.

The impact of the smart factory will bring organizational changes and therefore to labor contracts and industrial relations. In a scenario characterized, thanks to the domination of technology, by greater collaboration and the presence of high professionalism, rather than the mere elaboration of orders and directives, a work paradigm emerges in which the very dimension of the contract and the dependency relationship between worker and company is revolutionized.

Figure 5

4 5G: the big picture

5G will provide intelligent access in IOT and broadband wireless connections. Big Data and mobile will be key in enterprise market development. Social media and IOT platforms will be a disruptive wave. New social analytics and mobile tools will be key in the digital transformation scenario. The new ways of communicating, of people and companies, and the explosion of applications made available intuitively through the app store model, cause not only a continuous growth of data traffic, but also variations in the mix of types of traffic and more stronger end-to-end quality requirements.An in-depth analysis is available in the IoRoma technical magazine:

https://rivista.ording.roma.it/digital-transformation-2/

In urban mobility, we understand that mobile device interactions are passive as users accept information from social media and mobile apps, delivered from intelligent systems in cloud architecture. Next generation communication systems are expected to be intelligent in nature, as well as providing a platform for operators to effectively exploit their network resources in an era where spectral resources are at a premium.

The smart cities can be designed based on cognitive radio which is meant for spectrum sensing and spatial sensing. It also uses the massive MIMO and the heterogeneous network which uses small cells called Femto / Pico cell. The Digital Transformation and the 5G are two sides of the same coin and enable the new revolution of Industry 4.0 as examined in the article taken from the event on Industry 4.0 that is available on the journal IoRoma

5 Evolution of Telecommunication transmission infrastructure Beyond 5G: Software Defined Radio and Cognitive Radio technologies.

The Evolution of Telecommunications transmission infrastructures beyond 5G will be influenced by cognitive radio technologies & self-organizing functionalities.

The possibilities of integration between 5G technology and Cognitive Radio, will provide a series of benefits including greater energy efficiency, a reduction in interference and greater coverage both in the spectrum of licensees and in that of non licensees. The topic of Dynamic Spectrum Access (DSA) is thus treated in university research and regulatory activities in Software Defined Radio and Cognitive Radio communications in Italy and in international organizations, presenting the Cognitive Radio technology as an evolution of the SDRs and as valid solution to overcome the limit of availability of the radio spectrum. In general terms, Cognitive Radio is the intelligent technology that explores the spectrum by exploiting the holes of the unlicensed or underused frequencies and their spatial availability. In the 5G communication network, devices such as smartphones interact with the base radio stations of the cellular network and receive indications in which spectrum they can find more favorable conditions in terms of greater availability for frequencies and bit rates. This technology, capable of guaranteeing dynamic and no longer static access to the radio spectrum, however, presents complexities for its implementation, linked in particular to the aspects of legislation and regulation of access to frequencies.

One of the main problems of a Cognitive Radio (CR) and SDR architecture for 5G systems is the enormous energy requirement to support the cognitive abilities of mobile devices. CR has a high complexity linked to implementations with artificial intelligence chips and applications. Furthermore, there are further limitations related to the realization of CR for 5G that require devices with high computational complexity to analyze and perceive the entire spectrum range with good sensitivity and quality. However, this evolution of 5G with the integration of SDR / CR in its radio architecture, even if it now appears an uphill road, will become unavoidable to fully implement the IOT architectures. Smart City and for the smart factory in the Industry 4.0 scenario. The new "Next generation" communication systems are already born intelligent, and will provide operators with a platform that will allow them to make the best use of the scarce spectrum resource thanks to an etergenic network architecture that requires Cognitive Radio to be implemented. Smart cities may be designed based on cognitive radio which uses "spectrum sensing" and "spatial sensing". The "massive MIMO" antennas and the "heterogeneous networks" using the Femto / Pico cell "small cells" are used.

6 Dynamic Spectrum Access (DSA)

Both cognitive radio (CR) and the fifth generation of wirelless networks with 5G standards are considered the new technologies that will enable new business models: while on the one hand, Cognitive Radio offers the possibility to significantly increase the efficiency of the spectrum. used by end users (CR users) thanks to the use of unlicensed frequency gaps and the level of use of the available bands, on the other hand, 5G enables ultra-broadband interconnection with applications with Quality of Service (QoS) services defined for user classes differentiated for purposes and scenarios.

Figure 6

The growing demand for multimedia and internet access in portable devices has led in recent years towards an ever greater demand for access to the spectrum in certain bands, causing an overload of the frequencies involved. Cognitive Radio: regulation issues and Mobile Industry vision .In GSMA the debate is still open and starts from GSMA Mobile Policy Handbook The main concern is that Cognitive Radio and SDR technology will in no way reduce the need to harmonize and regulate the radio spectrum: "Cognitive radio technologies will not reduce the need for harmonized mobile spectrum anytime soon.

7 5G Cyber security challenges in a post-pandemic world

Accessing corporate resources remotely through virtual private networks (VPN) has traditionally led to a more secure access policy; the need to introduce remote work has resulted in more permissive VPN access policies, which is creating security risks that provide severe threat to corporate networks. We need to improve security based on passwords and move to multi-factor authentication. We can take this COVID threat as an opportunity to improve our security policy and delete old practices, such as passwords without security strong authentication rules, we have the opportunity to move on to more secure technologies. However, "multi vector" DDOS attacks occur at various levels and affect all architectural components according to precise strategies that aim to overcome defenses by saturating them to reach the user application such as in the smart factory. The figure expresses the coexistence of "multi vector" attacks at a conceptual level. Therefore, a cyber-attack on user applications affects 4G-5G mobile infrastructures with SDN, NFV and Cloud infrastructures

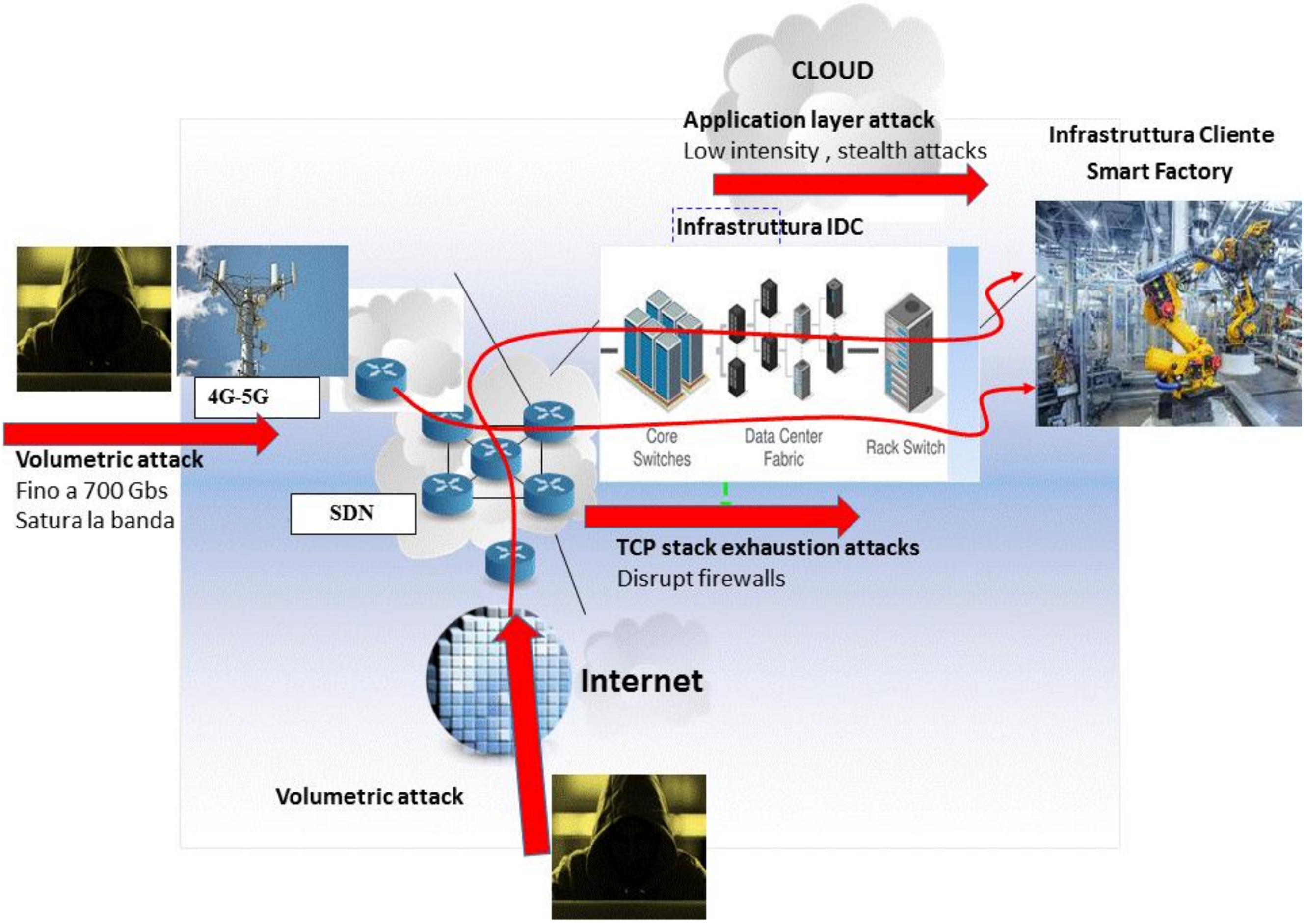

Figure 7

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The STRATEGIC project: Innovative automated analysis tools for After Action Review (AAR) using AI and modeling & simulation

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Abstract

During a training session using simulations, all information is recorded for replay, visualization and detailed analysis purposes. Classical After Action Review (AAR) tools offer many functionalities to zoom in on a specific moment or to give general feedback on the choices of the trainees. The materials trainers generally use are scores, videos and screenshots, which they have to enrich manually .

The STRATEGIC research project proposes innovative automated analysis tools, based on artificial intelligence and modelling & simulation. Our work focuses on three strategic pillars: :

• a narrative reconstruction of the causality of the events using a graph model. This helps in understanding the consequences of the trainee's choices and highlights the key events of the session, thus facilitating communication during the debriefing session.

• an automatic generation of enriched operational diagrams offering smart synthesis of the tactical situation and its history: local force ratio, tactical lines, main effects of missions, contextual units capacities, ...

• interactive pictures for alternative solutions exploration

Early results are so promising that the french land Army ordered many smart diagrams; not only for 3A and supervision of training sessions, but also for intelligence valuation. In the future it could be also used as a decision support & alert system at HQ.

1 Taking After Action Review (AAR) to the Next Level

1.1 Existing AAR tools for simulation-based training

Broadly speaking, a training session starts with a preparation phase, where the realistic operational environment is created, followed by an exercise phase where all the trainees take part in the simulation and, finally, a debriefing phase, also called After Action Review(AAR) where the stakeholders have an interactive discussion in order to understand what happened during the exercise and why, as well as how to improve or sustain performance in similar situations in the future. Duration and timing of the discussion are very important: too many details lead to a lack of concentration among the participants and inadequate timing tends to make the participants forget the real reasons that made them choose a specific course of action.

AAR refers to activities including verbal feedback, analysis of tactical situations, review of audio and video recording, and playback of the training session. Training can be prepared for an individual or group of individuals. The goal of the AAR is to provide feedback on performance during and after the exercise and to guide the trainees through the discovery of their strengths and weaknesses. The intention is for all those involved to discuss and learn from the information presented at the review.

Just as there is no one correct way to conduct an AAR, there is also no one correct way to automate an AAR. There are common requirements to be met in all types of training and AAR. Interviews with army observers/controllers at various combat training centers (Dyer, 2005) (Salter, 2007) clearly indicate that automation that improves training recall and diagnosis is desirable. Dyeret al (Dyer, 2005) noted that "AAR aids should assist the trainer, and should be used when they are "value added". The statement indicates that automated AAR should be geared toward assisting the trainer and not as a replacement for the trainer. According to (C.L Johnson, 2008), one of the biggest flaws of automated AAR tools is inability to determine cause and effect relationships and connections between events. Available AAR automations easily list events, but do not assist the trainer in linking these events to the mission plan.

Indeed, an effective AAR relies on accurate perception of the training events. As often happens when humans are involved, perceptions can be quite diverse among people viewing the same thing. Because computers and software are available to track or simulate battle participants, it is possible to present the ground truth of the situation in addition to the perceived truth during the AAR session. By allowing the trainee and the trainer to see the ground truth of the event rather than just their own perceived truth, the first steps of the learning process are begun.

1.2 Linear Logic (LL) and Planning for storytelling

In Artificial Intelligence, task planning is the problem of selecting an ordered list of actions, starting with a set of possible initial states, to achieve a particular goal state. It has numerous applications in robotics, scheduling, resource planning and even automated programming.

Physical behavior of a particular system associated with an action is summarized through a list of preconditions and a list of effects for the action, providing a discrete abstraction of system behavior. When an action is triggered, the environment is effectively modified in accordance with the described effects, eventually rendering other actions operationalizable depending on whether preconditions are now matched in the environment. Task plans based on such representation of action and change achieves a coherent sequence of actions with regards to causality, and has thus featured among popular techniques in the field of narrative generation and interactive storytelling: from a baseline representation of narrative actions or events (encompassing narrative material such as characters, objects, or even their knowledge or emotional states), stories can be represented, generated, and studied as a partially ordered plan of actions.

Among languages for representing actions for the use of planners are STRIPS, or PDDL. Using such standardised languages permits the use of a variety of planners, one example being for the generation of stories from raw material. In (Bosser 2010), Linear Logic (LL) has been proposed as an alternative to planning-based languages for the representation of baseline narrative actions and plot specification, based on the establishment of a strong connection between proofs in Linear Logic and action plans (Masseron Tollu Vauzeilles).

In LL, an action a can be encoded by means of the linear implication $\multimap$ a: $q0 \otimes \cdots \otimes qi \multimap r0 \otimes \cdots \otimes rj$, where qk and rk are resources of the simulation.

This expression means that all of qk will be consumed after performing action a, while all of r0 will be produced. For a to be performed, all of qk must be available.

While this may not be an off-the-shelf solution for the real-time generation of original plots using baseline descriptions such as in AI planning, it has the advantage of relying on a strongly grounded logical framework founded on a low level resource-based description, which on its emergence opened the door to establishing and verifying properties of stories represented as Linear Logic proofs (Bosser ITP 2011). Analyzing the flow of resources throughout the sequence of unfolding action also allows the automatic construction of fine-grained diagrams that display the network of contributing causes, and the relationships between actions in a story (Martens 2013).

1.3 Narrative debriefing for simulation-based training

The large amount of data generated during training using simulation may complicate the AAR. To remedy this, we propose to develop a narrative creation toolkit that will assist human explanations, in terms of a story (or narrative) describing a given simulation session, for all participants. The idea is to provide a semi-automated analysis of the session based on a narrative reconstruction of the (potential) causal links that exist between events that occurred in the simulation, and to include tools to support their structured presentation.

In the field of education or serious games, storification (Akkerman, 2009) is used to describe the creation of a causal structure by establishing links between narrative events. One of the challenges in these areas is the realization of systems to automate or semi-automate this activity in order to educate various user profiles. Conversely, studies in psychology of story understanding have also shown the importance of the perception of causal relationships between narrative events (Trabasso, 1985).

While modeling causality occupies a central place in Artificial Intelligence (AI) (Pearl, 2009), Narrative Intelligence's point of view is closer to commonsense reasoning: the narrator must select the events to be recounted, express the causal links among them, and select a level of granularity of such connections in order to make the final story meaningful. Contrary to classical approaches from AI, narrative intelligence tends to provide an explanation in a form that is assumed to be more accessible for a human user (Riedl, 2016).

Our aim was not to provide a fully automated story construction system, such as in recent machine learning approaches: our system must support the confrontation of different points of view during debriefing and cooperative learning activities. As such, it should help each user to construct, and explain their own subjective narrative, depending on the information they had access to (depending on the roles of the participants, this may vary widely) and their decision rationale. The tutor in charge will have access to all information, and their constructed narrative will also differ.

Narrative refers to the presentation of a coherent sequence of events that combine to tell a story. According to (Mani, 2013), computational narratology is the study of narrative from the point of view of computation and information processing. It focuses on the algorithmic processes involved in creating and interpreting narratives, modeling narrative structure in terms of formal, computable representations. Its scope includes the approaches to storytelling in artificial intelligence systems and computer games, the automatic interpretation and generation of stories, and the exploration and testing of literary hypotheses through the mining of narrative structure from corpora.

Narrative structures are an important field of research in Artificial Intelligence, and have been for a long time. This is due to their ability to make knowledge explicit (Schank 1995, Reiter 2000). Technologies resulting from Interactive Narration have created a lot of interest in the fields of simulation or serious games (Cavazza,2016). By allowing the representation of scenarios and their progression, while preserving the coherence of a story and propagating the consequences of user actions, they permit the exploration of the knowledge represented by these stories. Thus, the formalization of a narration is a structure of knowledge which extends the logic of actions, providing a framework to represent the causal and temporal aspects relating to a given situation.

The narrative representation obtained provided by these technologies offers an innovative support for the discussion between trainees and trainers. It offers a contextual view of events and the ability to understand the causes and the consequences of each event or choice made by the trainee.

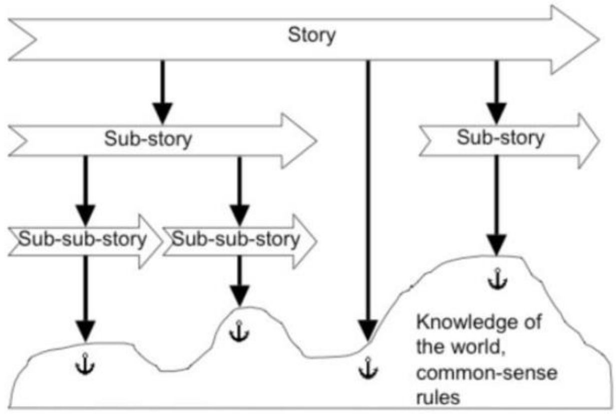


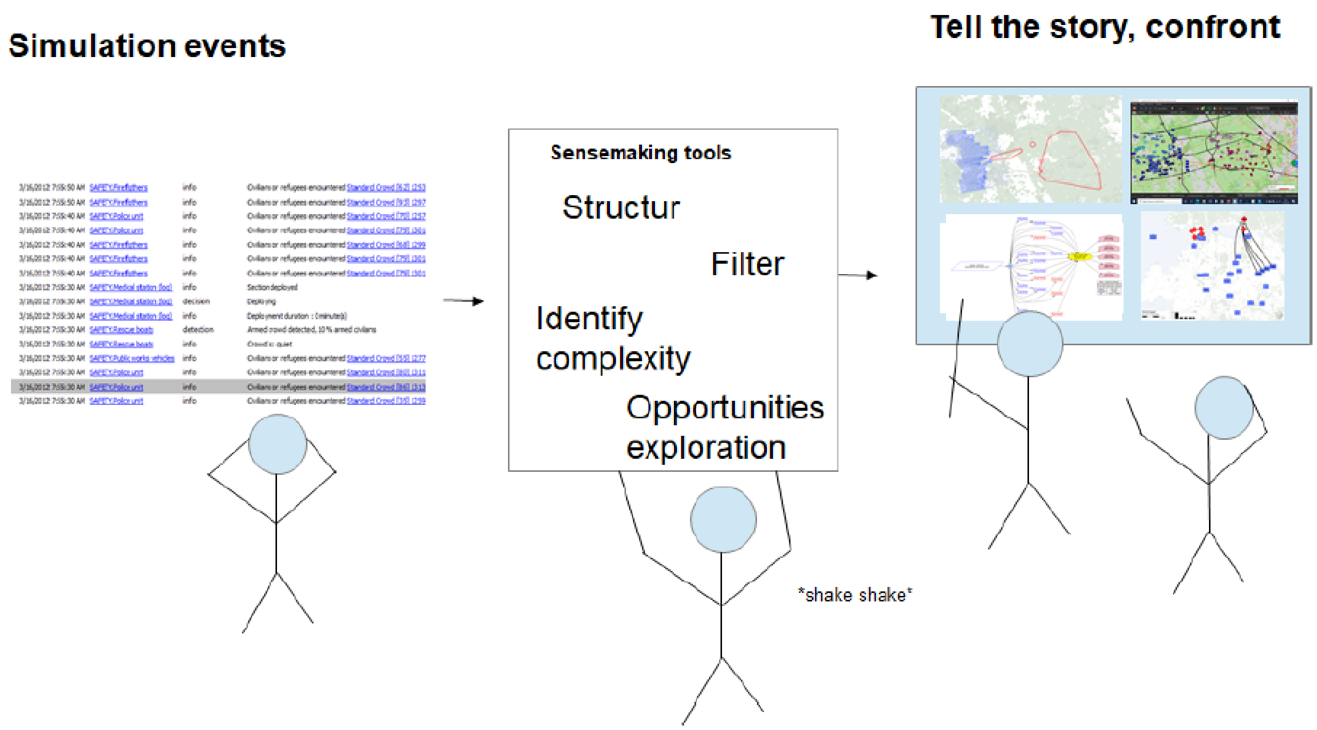
Figure 1 - Verheij's visualization of hierarchical narrative grounded in common-sense, adapted from the representation of Wagenaar, Van Koppen and Crombag (1993)

According to (Whitman Richards, 2009) the figure 1 embodies what might be considered the kernel of all narrative representations. At the top, the large arrow represents the main progression of the story: a linear set of events that proceeds, one after another, from start to finish. Beneath that are smaller arrows, representing smaller portions of the story that could be considered as stories in their own right. This nesting can continue, becoming relatively elaborate, until reaching a point where the stories represent a common-sense knowledge of the world, suggesting connections between argumentative and narrative elements (Bex, 2007). Hence, to first order, there are three common denominators amongst representations considered: (1) narratives have to do with sequences of events, (2) narratives have hierarchical structure, and (3) they are (eventually) grounded in a common sense knowledge of the world.

2 The Strategic Project

2.1 Objectives of the STRATEGIC project

As explained earlier, during a training session using simulations, all information is recorded for replay, visualization and detailed analysis purposes. Classical After Action Review (AAR) tools offer many functionalities to zoom in on a specific moment or to understand and give general feedback on the choices made by trainees. The material usually available to communicate with trainees are numerical indicators, videos and screenshots, all of which have to be manually enriched.



The STRATEGIC research project proposed innovative automated analysis tools, based on artificial intelligence and modelling & simulation:

● a narrative reconstruction of the event's causality in the form of a graph of events. This facilitates the understanding of the consequences of the trainee's choices and highlights the key events of the session and thus supports the communication during the debriefing session.

● an automatic generation of enriched operational pictures offering a smart synthesis of the tactical situation and its history: local force ratio, tactical lines, main effects of missions, contextual units capacities, ...

● interactive diagrams supporting the exploration of alternative solutions.

2.2 SWORD, a constructive simulation for military training

The training software we used, SWORD, relies on a constructive simulation which allows brigade and division command staff to become immersed in large-scale conflict scenarios such as stabilization operations, terrorist threats or natural disasters. It simulates a diverse range of situations in realistic environments and lets trainees lead thousands of autonomous subordinate units (at platoon and company levels) on the virtual field. Agents can receive operation orders and execute them without additional input from the players, while adapting their behavior accordingly as the situation evolves.

Models capturing such behaviors comprise two components: algorithms that make agents perceive, move, communicate and shoot, and the description of the capabilities of the underlying equipment. The simulation session database contains three different types of information:

● Data regarding the physical element: components of units are described here. Because the simulation is a constructive simulation most of the features of the equipment or units are described by their effects or their capacities. This facilitates their description in terms of action and change.

● Initialization data for the scenario contains the following information: terrain, order of battle, weather, data provided by the simulation such as events, knowledge obtained by the agents, etc.

● Data generated by the simulation describes the evolution of the situation: information describing the evolution of the game containing all events, knowledge about the environment, and all mission reports.

All this information is presented to the participants as a set of messages exchanged among the agents during the simulation that contains all the information described above. An extract of the simulation is shown below:

[07:29:47] - Report - ENG.Counter mobility platoon: Disembarkment started

.....

[07:30:17] - Report - INF.Mortar troop: Unit detected at

.....

[07:30:17] - Report - INF.Rifle platoon: Unit detected at ...

2.3 Functional architecture

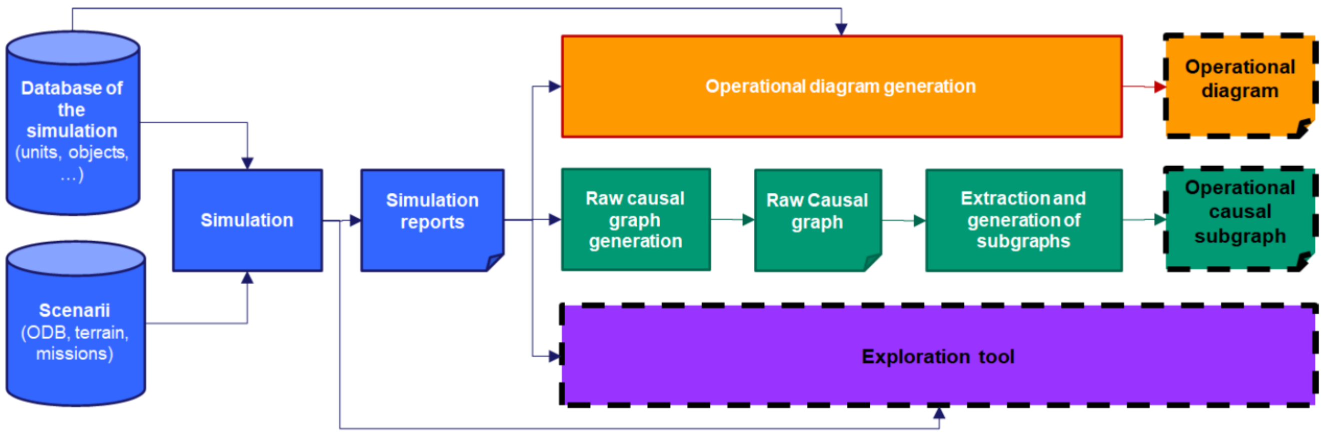


Figure 3 Functional architecture

Our work focuses on three main areas:

● an innovative and alternative conception of the representation of the tactical situation according to an operational focal point, exploiting the ontology of the simulation (effects of missions, role of units, ...) in a novel manner, and its models (ex: capacities of units, balance of power, ...), in order to allow the production of operational pictures illustrating the tactical situation at any moment in time.

● an analysis, interpretation and structuring of the reports of events resulting from the simulation in a form that allows for the employment of causal relationships: this work includes the reflection around the causality model to be adopted, as it had to be compatible with the information in the reports, and expressive enough to support an interactive construction of the explanation.

● careful consideration of the human-computer interface required to generate

o relevant and actionable narrative subgraphs

o intuitive and intelligible operational diagrams

2.4 Genericity of the solution for a variety of different scenarios

This work was based on different simulation scenarios with an increasing level of complexity: the first scenarios involved a very small number of units but still generated examples of reports allowing the implementation of the first version of the raw graph. We were thus able to program a first processing of the reports, enabling an elimination of superfluous information, retaining only the reports concerning resources and actions.

Next, we used other more operational scenarios: Egypt, Sweden and Menil Anelle. These three scenarios, ranked in order of size, made it possible to scale up the work carried out.

	Simple scenarii	Egypt	Sweden	Menil Annelle
Number of units	2-4	62	120	508
Size of the terrain (km)	SO	96*111	103*54	109*70
Duration (ticks= 10s)	SO	1807	3244	1662
Number of companies missions	0	91	325	670
Number of platoons missions	2-4	167	607	1620
Number of enemies detections events	SO	121	191	488

Figure 3 Description of the scenario

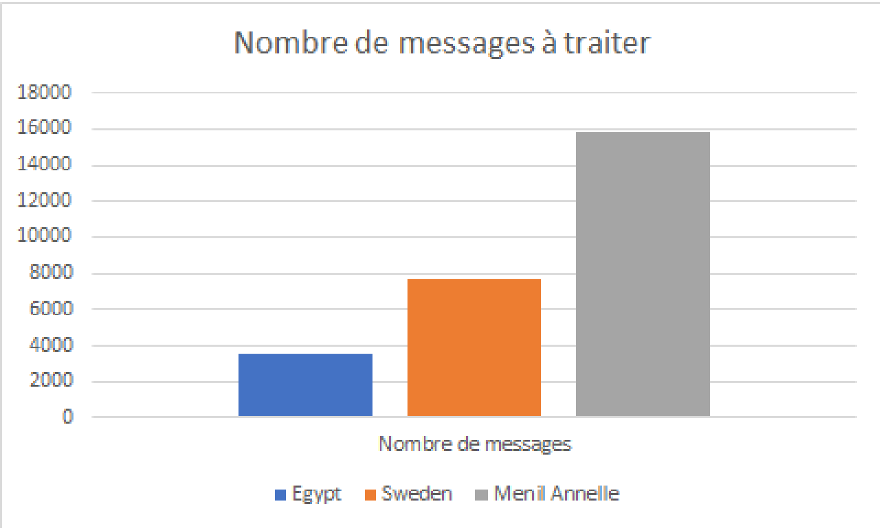


Figure 4 Number of events/reports to compute

The use of many different scenarios allowed us to validate the genericity of our technical and algorithmic solutions: different terrain, different units, different missions, …

3 Narrative Reconstruction of the Causality of Events

The construction of the narrative support tool involves two steps: first, a raw causal graph is constructed by translating the simulation's reports into events linked by causal relationships, then subgraphs are extracted and automatically reworked in order to be readable.

3.1 Construction of the raw causal graph: a Linear-Logic based approach to story construction and analysis

The formalization of narratives is a problem that has often been approached in Artificial Intelligence from the perspective of representation and Reasoning about Action and Change (RAC), starting from the atomic modeling of a narrative action, and describing its impact on the environment. (Anne-Gwenn Bosser, 2010) & (Anne-Gwenn Bosser P. C., 2011) use Linear Logic (Girard, 1987) in modeling which has led to formal approaches to story analysis and property verification. Among other advantages, this approach allows for the modeling, in a declarative way, of each event, by describing its impact on the environment in terms of consumption and the production of resources. This has led to systems where stories generated from a linear-logic based declarative specification could be described by reconstructing causal relationships between events and displayed in the form of causal diagrams (Chris Martens, 2013), (Chris Martens J. F.-G., 2014).

We have produced a formal description of the translation of the traces of SWORD events into atomic actions, thereby building blocks of the raw graph. These actions represent exactly what, in the simulation, was changed by the triggering of the corresponding events. This component provides both a method for the translation of SWORD traces into actions in the raw graph, and the construction of a graph of contributing causes. The algorithm is based on the sequential processing of the state of the simulation over time, which in the future will allow it to build the above on-the-fly as the simulation progresses (through integration in SWORD rather than as a separate component). This state maintains at each moment of the simulation the entire operational status of the simulation units. as well as the knowledge units have about each other (visibility). The current implementation uses Go, and the process takes about 500ms on a mid-range computer for our most complex scenario. The graph produced is described in dot and json formats which facilitates their processing by standard tools (visualization, processing libraries).

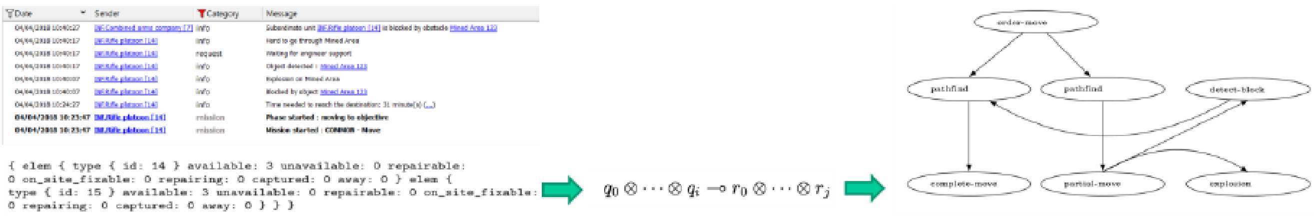


Figure 6 From the simulation events to the raw causal graph

The different kinds of events and reports produced by the simulation (position & state of the units, firefights, detection and move events, …) have been translated into linear logic formulas. The diagrams obtained retrace the contributing causes of the events. The diagram above shows an example of a graph computed using a simple scenario as a basis: a unit moves and encounters a mined area.

For example, a move can be caused by a mission, or damages can be caused by an explosion or firefights:

$$
\begin{aligned}
\texttt{order-move:}\quad & location(Y) \multimap mission(id, move(Y));\\
\texttt{pathfind:}\quad & mission(id, move(Y)) \otimes pos(id, X) \otimes Context(id, C) \multimap mission(id, move(Y)) \otimes pos(id, X) \otimes \\
& Context(id, C) \otimes path(X, Y);\\
\texttt{partial-movement:}\quad & mission(id, move(Y)) \otimes path(X, Y) \otimes pos(id, Z) \otimes Y \neq Z \multimap Y \neq Z \otimes mission(id, move(Y)) \otimes \\
& path(Y) \otimes pos(id, Y);\\
\texttt{detect-block:}\quad & path(X, Y) \otimes pos(id, Z) \otimes mine(Z) \multimap knowledge(id, block(mine(Z)));\\
\texttt{explosion:}\quad & pos(id, Z) \otimes mine(Z) \otimes context(id, C) \multimap pos(id, Z) \otimes damages(context(id, C));\\
\texttt{pathfind:}\quad & mission(id, move(Y)) \otimes pos(id, X) \otimes context(id, C) \multimap mission(id, move(Y)) \otimes context(id, C) \otimes \\
& pos(id, X) \otimes path(X, Y)\\
\texttt{complete-movement:}\quad & mission(id, move(Y)) \otimes path(X, Y) \otimes pos(id, X) \multimap pos(id, Y)
\end{aligned}
$$

Figure 7 Example of linear logic formulas

3.2 Construction of the narrative graph

- The raw causal graph produced after the process described above is not directly usable as they are too big, even for small scenarios. One aim of the project was to provide a set of tools, based on generic or ad-hoc heuristics, to render it tractable for human understanding. Here are examples of heuristics we used for aggregating nodes of the raw graph into higher level narrative events or suggest entry-points for the analysis:

- - The relationship between the number of causal relationships on a set of events and the importance of perceiving an event in a story has been discussed in (Mazlack, 2004). This was used as an heuristic to highlight events of interest .

- - Spatio-temporal zones where events involve attrition were likely to correspond to exchange of fires, with many interactions between units and events. We used this as a heuristic to simplify and summarize a number of nodes into high-level ones.

The component thus offers a solution for the representation of the simulation's events in the form of a more streamlined causal graph in order to support the narration. It first applies ad-hoc simplification heuristics and clusterization algorithms on the raw causal graph. This allows us to obtain a higher level graph, called the "narrative graph" with a greatly reduced size that makes it computationally manageable in interactive time.

	Raw Causal Graph		**Narrative Graph**	
Test Scenario	**# nodes**	**# links**	**# nodes**	**# links**
Egypt	1902	4021	326	503
Sweden	5760	12620	973	1429

Smart filters are then applied, and offer partial views of the narrative graph. For example, one can ask for the history of a specific unit or the inventory of events that results in getting a specific event of the simulation. The result details: the missions of the units, their moves, the enemies detected, firefight events and damages… Views can also be enriched with their temporal and spatial extensions.

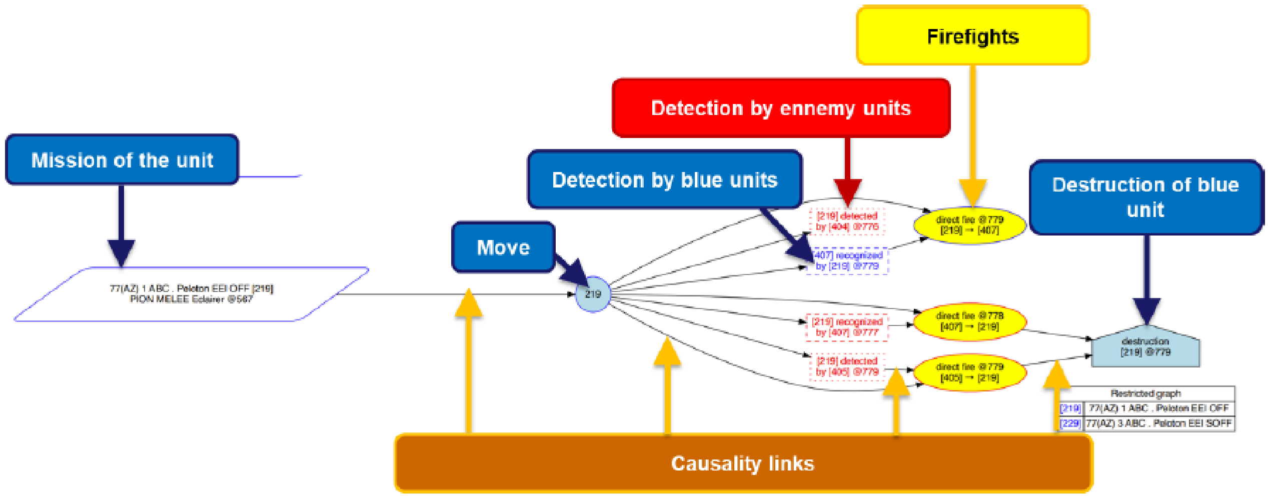


Figure 8 Narrative graph representation example: a focus on the history of a unit

Some heuristics that we considered as promising, such as the use of force ratio shifts, ultimately proved to be ineffective and redundant in spotting and factoring landmark events regarding the analysis of the causal centrality of certain nodes. On the other hand, simple mechanisms based on their spatio-temporal proximity for bringing together complex actions have proved to be very effective. They also naturally offer the highlighting of the salience of certain events from an operational point of view. From a performance point of view, the generation of the complete narrative graph may take a few minutes on the larger scenario, but once generated, the requests receive rapid responses.

4. Automatic Generation of Enriched Operational Diagrams

In order to better understand the tactical context at a specific moment in time, to support the discussion and to offer a shared comprehension, we decided to propose smart diagrams based on the doctrinal decision parameters or directly inspired by operational synthesis generated at HQ for debriefing purposes.

4.1 Occupying The Terrain

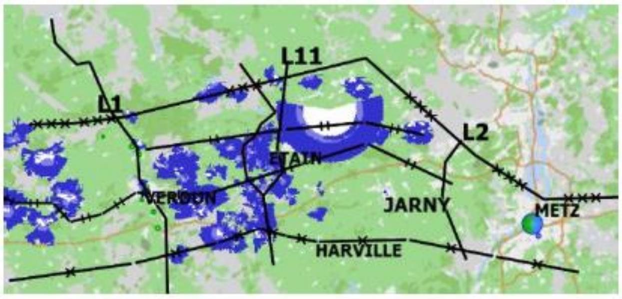


Figure 9 Contextual perception capacities

The system calculates the total area occupied by all units, the entire perception zone based on available equipment, the current missions of units, and the potential area covered by fire. These calculations can be performed on the basis of the hierarchical level of units, their equipment capacities, current missions, and positions. We directly used the capacities module of the SWORD simulation in charge of the calculation of the potential effects of the equipment of the units. Moreover, to provide an indication of the global force deployed at a glance, calculations of the density of forces could be added.

4.2 Local Force Ratio

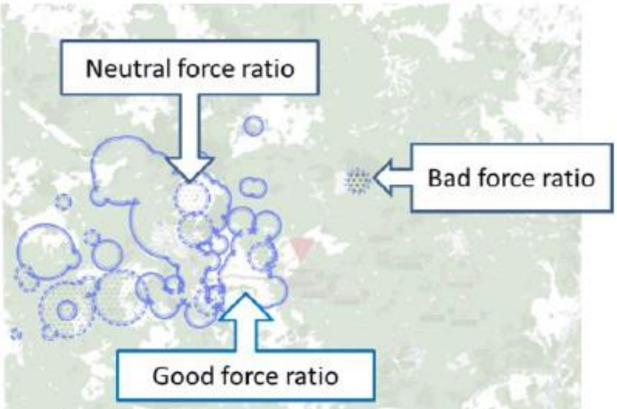


Figure 10 Local Force Ratio

The simulation calculates the force ratio of each agent based on its knowledge of the tactical situation. This is used as a decision-making parameter by autonomous units to help them determine whether they are likely to be able to accomplish their mission, or whether the situation is considered to be too dangerous (as written in the use of the force doctrine). It is therefore possible to offer a dedicated view of the local force ratios, which provides an insight into which forces, or area, may have required reinforcements.

4.3 Local Force Ratio

Commanders use common offensive and defensive control measures to synchronize the effects of combat power. Understanding and using commonly understood control measures enables commanders and staff to develop and publish clear and concise mission orders, as well as direct tactical actions quickly, with minimal communication during execution.

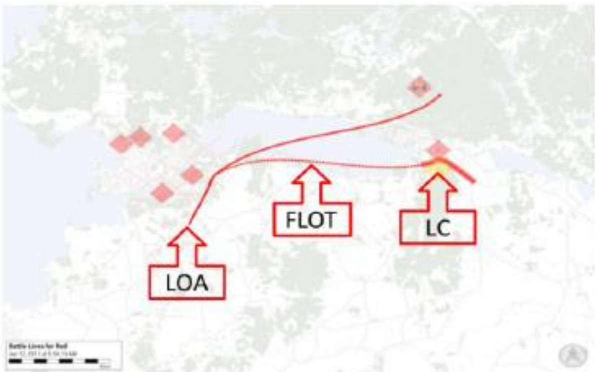


Figure 11 Tactical lines

Based on current missions, knowledge of enemies, and combat capacities of units, we are able to generate on the fly a global maneuver summary, which includes a calculation of tactical lines, such as the :

- Forward Line of Own Troops (FLOT) that indicates the most forward position of the forces. The FLOT normally identifies the forward location of covering or screening forces.
- Limit Of Advance (LOA) is a phase line used to control the forward progress of the attack.
- Line of Contact (LC) is a general trace delineating

the location where friendly and enemy forces are engaged.

● The forward edge of the battle area (FEBA) is the foremost limit of a series of areas in which ground combat units are deployed to coordinate fire support, the positioning of forces, or the maneuver of units, excluding areas in which covering or screening forces are operating (JP 3-09.3). The Army uses a FEBA only during defense. (Headquarters, 2019)

4.3 Local Force Ratio

Figure 12 Effect applied

According to the past and current missions of the units, it is possible to provide a view of the main effects exerted by units on the field. For this purpose, the missions have been classified according to their main goal effect on the field and on enemies. In this first version we focused on four main effects: the intelligence, the offensive effect (attack), the defense effect (including engineering defense works) and the support. The result is an interactive layer that offers a way to choose the effect and the side. Naturally, the line of the front with an indication of the available support, the defense positions, and the scouted zones, all appear.

To take this analysis further, we could provide a maneuver view that relies on the major expected effects regarding the enemy and terrain. For example one could produce a layer that differentiates between zones that must be recognized, conquered, controlled, etc., or enemies that must be eliminated or stopped. This could be achieved through the interpretation of the advancement of current missions, and the nature of planned missions.

5. Alternative Solution Exploration Tool

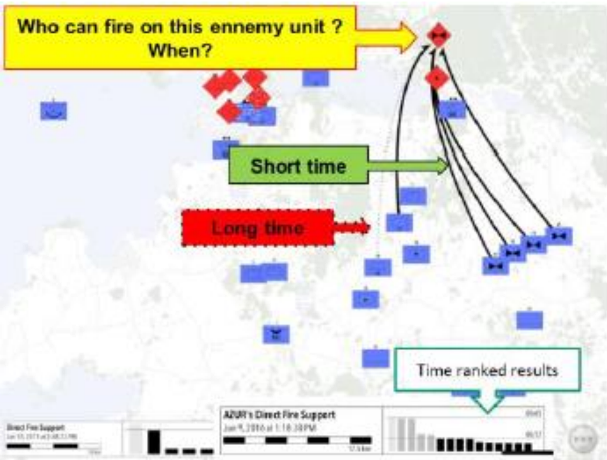


Figure 13 Delay to support calculation

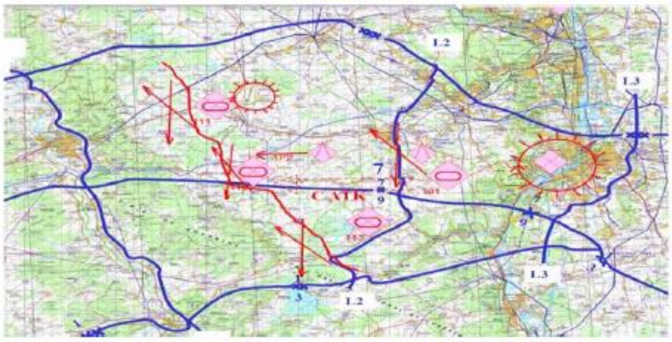
The idea here is to offer an easy way to explore possible alternatives when managing the tactical situation and in this way propose the foundation for counterfactual analysis. For each unit on the battlefield, we provide a calculation of the time taken to reach a position to support a unit facing an enemy. To achieve this, the simulation calculates the best route for each unit. This calculation takes into account all equipment capable of direct or indirect fire, known enemy positions, the terrain, friendly and enemy engineering works, tactical limits, etc.

Thanks to the simulation, it is possible to easily identify who could support a unit or fire at an enemy and within which timeframe, considering the terrain and the capabilities of the units.

6. Exploitation of the Results

6.1 Exmple of an Operational Use Case

6.1.1 Simulation Scenario



Blue objectives:

● Conquer the zone between lines L1 and L2 by overpowering each encountered enemy.

● Conquer the L2 line before June 17th.

Enemy objectives :

● Install two battalions on the defense line.

● Create large connected mined obstacle zones between the river and the defense line.

● Render the west of Metz a no-go zone, and retain control of the Etain airport.

The blue operation is a success, despite heavy losses. It appears that the bulk of the blue losses are made up of platoons from a reconnaissance battalion. It would therefore appear beneficial to identify the causes of these losses, and determine whether they could have been avoided.

6.1.2 Understanding the Cause of Heavy Losses

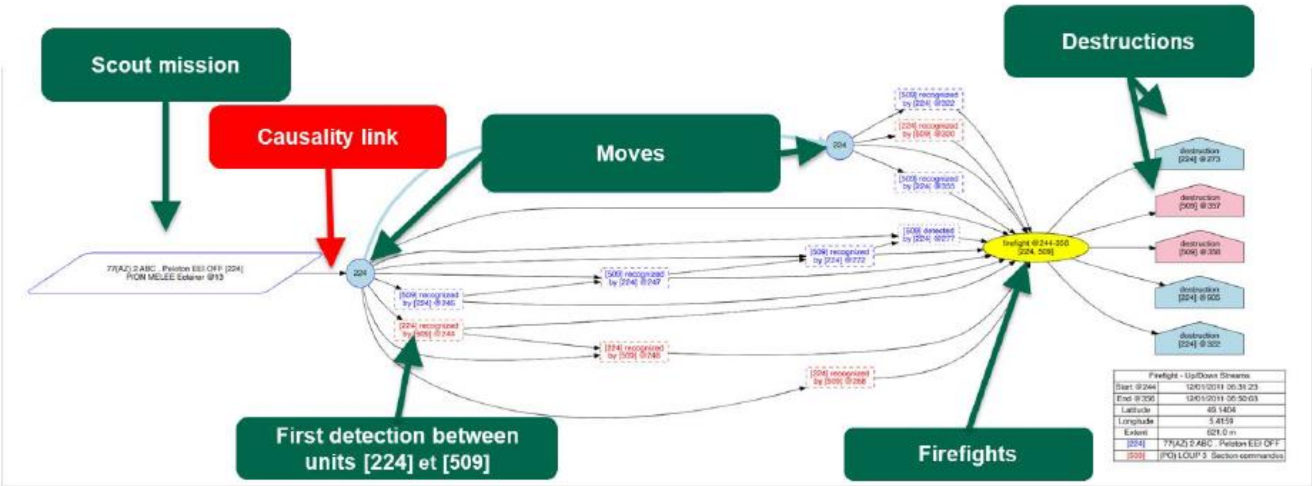


Figure 15 Narrative graph focused on unit 224

To this end, we generated a narrative graph focused on one of the destroyed scout platoons, the [224] unit.

This option makes it easy to understand and recount the unit's story: it received a scout mission at 11h35 (tick 224), at which point it moved, and two minutes later encountered the enemy unit [509]. The two units detected each other, exchanged fire, and inflicted damage on each other between 11h43 (tick 273) and 12h21 (tick 500). Having a view of the tactical situation at this moment consequently appears highly beneficial:

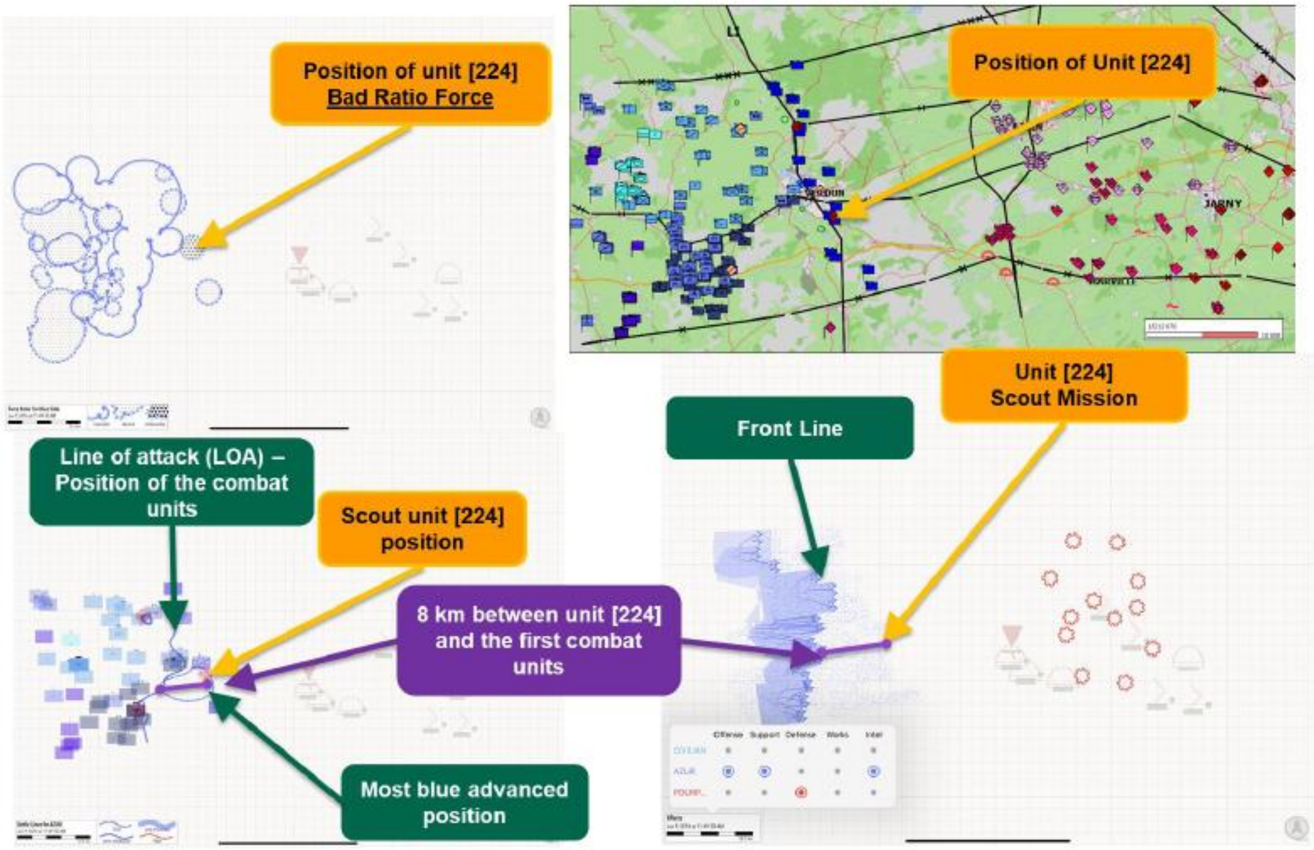


Figure 16 Tactical context of unit 224 during the firefight

These operational diagrams offer a view of the tactical context when the scout unit [224] is being shelled. The force ratio diagram indicates that it was isolated: the two other diagrams show that it was on a front more than 8 kilometers from the first combat units.

6.2 Immediate and further exploitation perspectives

Following multiple demonstrations and presentations of the project to operational and MOD staff, a variety of profiles were highly interested in the project. On one hand, the teams in charge of the SOULT training program have therefore ordered "smart diagrams" from MASA for mobile exercise supervision and AAR. On the other hand, the section of the Digital Office of the Land HQ(EMAT), in charge of analysis and operational research, also ordered smart diagrams related to the enhancement of intelligence. This section's mission is to analyze digital data, both organic and operational, to present objective and consolidated views. Two capabilities have been ordered: the display of the contextual detection capabilities of a camp and the interpolation of the future enemy positions.

To create his/her own version of the course of the simulation and give a point of view, rather than just building a narrative graph, the user could also receive automatically simplified portions, and combine them with the other views of the AAR tool: a map, smart pictures, indicators… Then, the exploration of counterfactual "what if" scenarios would also be possible from the simulation interface, thanks to the replay function that allows you to start the simulation again from a given timestamp. The trainee and trainers could then modify the course of action and evaluate the benefits of these changes. This counterfactual exploration offers the possibility to go beyond a simple understanding by identifying the contributing cause and events which "if they had happened in a different manner would have changed the outcome of the simulation": it is this type of simulative reasoning that underlies the human causal interpretation.

To conclude, the use of this set of tools for sensemaking purposes in the context of decision support is an avenue that needs to be explored. Not only are these tools naturally adapted to the needs of a command post, but it is also possible to think further ahead and dynamically process information from the battlefield to prioritize, alert, contextualize and calculate their consequences. Indeed, by creating a digital twin of the battlefield, and integrating these innovative tools, it would be possible to:

● Contextualize the information from the terrain: prioritization of information and automatic sending of alerts through intelligent information processing. Indeed, depending on its tactical context, the same information will not have the same meaning. For example, the report « Enemy unit detected at XXX position » may have totally different meanings according to the position and the context of this detection

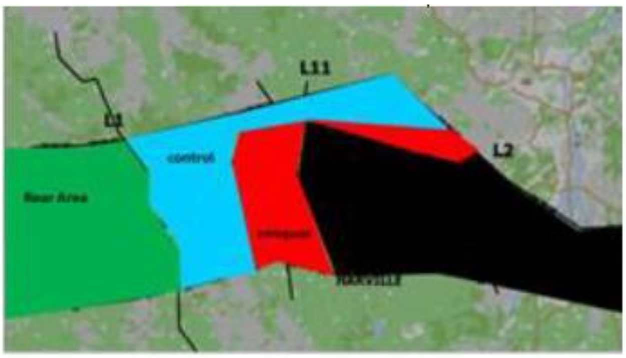


Figure 17 Context of the information

➢ In the black zone, to reconnoiter, means that the scout missions are going well.

➢ In the red zone, to conquer, an increase in the number of enemy units could mean the arrival of reinforcements and therefore a force ratio switchover.

➢ In the blue zone, to be secured, new enemies should not remain in this area, it means that remaining enemy forces were not all evaluated.

➢ In the green zone, that is secured, enemies in this area should result in a serious alert being sent.

● Calculate and alert on the consequences of events: automatic alert if a current (or planned) mission is compromised by the evolution of the tactical situation. For example, the destruction of a bridge can compromise medical support or require the preparation of a new logistical route.

● Calculate smart indicators for mission monitoring: as explained earlier, it would be possible to compare the current situation to the expected one or automatically compute the reports from the field to evaluate efficiency, the evolution of events, or the risks from a specific mission.

● Identify chain of events : a study has explored the use of classification techniques to format the raw graph on a data set test using machine learning methods. These methods would then not be used for the construction of the raw graph, but we propose to explore this avenue to perform manipulable "summaries" of the graph. The contribution of machine learning methods to facilitate the understanding of this graph could be deepened and in particular be used to:

o Determine the probability of the occurrence of a sequence of actions

o Detect unlikely sequences (threshold value)

o Predict the rest of a sequence

Many AI applications requiring trust start to turn to these methods, especially when the core of the technology remains based on symbolic methods and machine learning methods are applied to the processing of the raw graph.

All innovative solutions proposed here for decision support require two principal prerequisites:

1) a database containing all friendly equipment, plus presumed enemy equipment. Descriptions of all types of equipment must be accompanied by effect descriptions, to enable the simulation of the battlefield.

2) the integration of the command and control systems within the tools described above, with a view to importing all data into the simulation: unit positions, logistic states,

enemy knowledge, engineering work, NRBC zones, available missions, etc. We then have to design a data representation that provides an easy-to-understand, intuitive display of processed information.

7. Acknowledgments

This paper is based on the STRATEGIC research project funded by the Direction Générale de l'Armement (DGA) through the ASTRID Maturation program.

8. Conclusion

To conclude, narrative graphs used for simulation based training can be simple, or extremely complex. They let us:

• Explain the story of a unit

• Understand the role of all the units involved in a phase or firefight and its context

• Visualize the role of the units in the maneuver and assess their importance (a mission may or may not have multiple consequences)

So far we have focused on combat units and more specifically on the following events: mission, fire, movement, detection, damage. We need to add other types of units, missions and events: logistics, engineering, ... and offer an interactive graph path to obtain a global and detailed view. A learning algorithm could then propose automatic simplifications of the graph.

In addition, in order to understand the overall tactical context at an identified moment, we offer innovative and alternative views of the tactical situation, offering:

• A calculation of the capacities of the units on the ground according to the tactical context (current mission & speed of unit, weather, experience of the unit…)

• A calculation of the main effects applied on the terrain according to the missions assigned to the units

• A calculation of the force ratio (or units' local strengths) based on their knowledge of the enemy

• A calculation of the main tactical lines (FLOT, LC, LOA)

Some work has already been commissioned by the Army in a framework that goes far beyond the scope of the AAR.

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RAS synthetic environment using LVC M&S architecture

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Abstract

The employment of Robotics and Autonomous Systems (RAS) and robotic swarm in the future military operational environment is going to be one of the main challenges to modern warfare. Modelling and Simulation (M&S) technology allows to support Concept Development and Experimentation (CD&E) activities to develop new robotic autonomous capabilities, like robotic platforms, human-machine teaming interactions, Command and Control of robots, Artificial Intelligence for mission planning, decision support and self-training of robots and robot swarms.

The next step of the project was conducted on SWORD constructive simulator of MASA Company, where the main idea was to adapt the SWORD powerful capabilities to RAS entities in military operations, building a specific operative vignette for a proof of concept.

The combination of these aspects was born through an idea to adapt SWORD main features to automatic processes in a military operation involving RAS systems. The main task was to create a versatile synthetic platform able to develop and experiment RAS functionalities from technical, operative and informative point of view, for concepts and capabilities development.

The proposed project can be analyzed as a black box with inputs and outputs, where the SWORD RAS platform performs calculations exploiting the internal logic functions implemented inside SWORD algorithm engine. For this task, the platform developed, although has been realized according a scenario consisting of a specific operative reconnaissance vignette, it was designed in order to be flexible and parametric. In addition, an architecture of a synthetic environment is proposed in the capability development field of RAS systems, involving, besides SWORD RAS tools, also expert simulated systems (e.g. Matlab/Simulink and/or CEMA simulator) in order to investigate specific area of interest (e.g. swarm logic and/or robotics counter-measures). Implementing a synthetic-real bridge, for Live capability of the architecture, a project is proposed finalized to an electronic board development, called LoA implementation board. The mentioned board could be able to interface with synthetic environment RAS in term of behavioral code translation and with Robotic Operating System (ROS) in order to transform a Commercial off the Shelf (COTS) unmanned in a RAS platform, with defined autonomous functions.

***Keywords**: Behavioral codes, RAS, synthetic environment, LVC.*

1 Development of behavioral codes for the simulated RAS entities

The proposed platform represents the initial synthetic environment where different types of military operations using RAS would be verified, validated, and experimented on. The modelling and simulation RAS would not only allow for the development of new concepts with elevated technological weight, but also for the defining and development of peculiar doctrinal elements concerning the use of the RAS systems inside military organizations.

From a technical standpoint, a wargaming RAS with different teams could be implemented, for example, operators working on different simulators of the platform could implement behavioural algorithms in a RAS entity. This would serve for the goal of developing and analysing different course of action in the use of autonomous robotic systems and to consent for the improvement of behavioural logic inside the systems (Robotic Wargaming). Multiple simulations would allow for the acquisition of multiple cases for the training of the RAS platform modelled on the ample spectrum of causalities, reducing behavioural error verifiable with a processual algorithm.

The engineering capabilities applied to the modelling and simulation context, consisting of the characterization and projection of behavioural code, would give valid and essential aid in the development of real prototypes. Modelling and simulation used in the development of technological capabilities results in a significantly important process for the transformation of the military forces inside the increasingly complex and multi-factorial scenarios.

This platform could consent for the development of concepts and elements of a real RAS system. The development of a real physical object (prototype) could follow the process based on the following steps:

- identification of an unmanned platform (UAV type) based on an “open” platform to which different sensors can be connected (e.g., optical, infrared, radio frequency, radar, sound, lidar) for better versatility of use by the platform;

- modelling of the unmanned platform with the leading physical parameters to acquire the complete dynamic of the simulated entity and reach the maximum correspondence with the real platform;
- modelling of all sensors in the unmanned platform to verify the efficiency of performance with cases recreated inside the constructive environment;
- design of the behavioural algorithms (e.g., through LUA code) with defined execution priority, referring to the level of autonomy that needs to be reached in the platform. The projected algorithms will be tested inside the multiple simulations, fulfilling a **technical validation** activity when the technical-operative requisites are present;
- movement of the algorithms inside the electronic board (e.g., Field Programmable Gate Array and/or microcontrollers) adaptable and consistent with the unmanned platform to supply with the different RAS capabilities, in terms of behavioural processes to follow. In this context, modelled and simulated entities in a synthetic environment, will be tested in realistic conditions realizing an **operational validation** of the system.

The procedural flow is the base of capability development of a RAS system through M&S activities. This flow is presented in a schematic manner in Figure 1, placing weight on the different technical and operative phases that a synthetic platform could provide and to the respective interactions between different states.

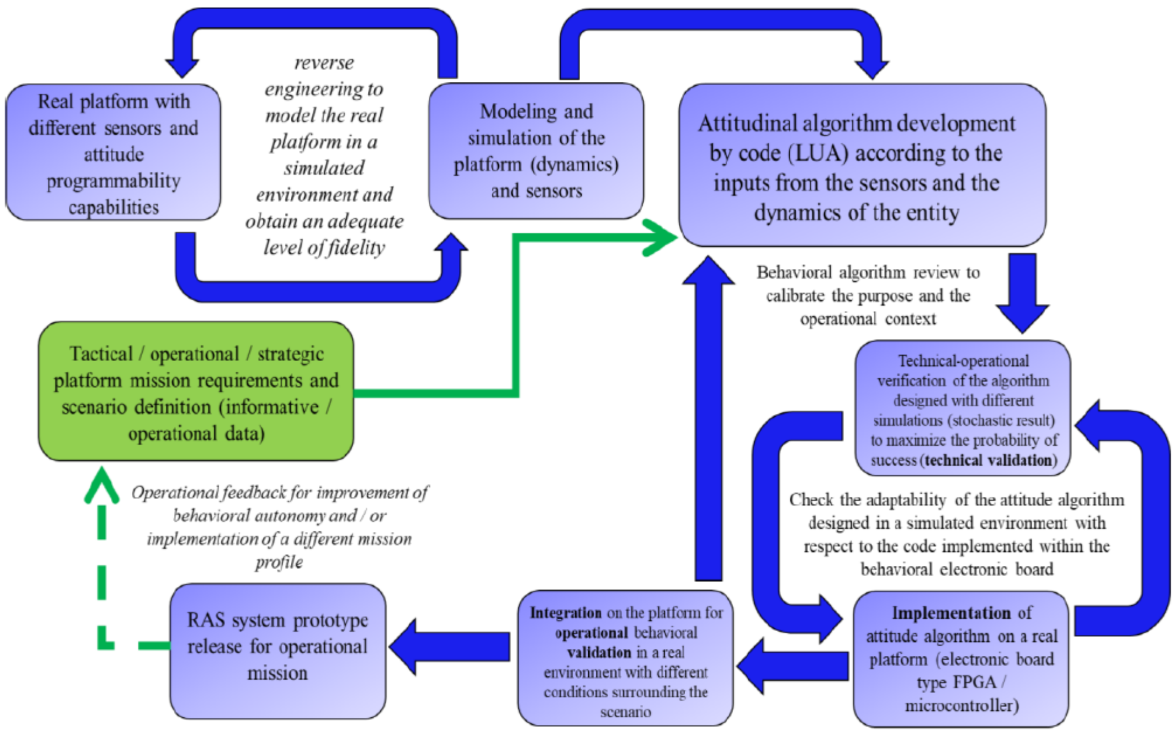

Figure 1. Procedural development flow of RAS capabilities with the aid of modelling and simulation for the consolidation of functionalities of the behavioural algorithms implemented on a RAS platform and verified with unique conditions of the scenario

Beyond the conventional use of the modelling and simulation tools, in support of decision making and training, the following relation develops an evolution of the synthetic platform with specific declination toward RAS capabilities in an unmanned platform, or in the development of compartmental codes, placing the turning point in the capability development setting. In this case, it is considered appropriate to highlight that, through the development of design capabilities of behavioural algorithms on the platforms modelled inside the constructive setting, it was possible to develop a different concept and point of view on the use of modelling and simulation tools for the study, analysis, and potential inhibition, of procedural flows inside the decision-making engines of RAS. The development of behavioural codes on RAS platforms could conduct the following lines of actions in the scope of the development of a RAS platform for military operations:

- through reverse engineering on the algorithms that were implemented in the behavioural board that references autonomous platforms, conducting a similar behavioural translation inside the model in the synthetic environment, to test and validate the RAS' behaviour, in different conditions around the scenarios (physical, operative, technical, and informative), consenting for the consolidation and/or integration and/or discarding of these features. This activity would require an implemented and synergistic study with the Company that constructed the RAS platform of interest;
- develop behavioural algorithms in a simulated environment, on the base of higher operative and technical cornerstones defined, in order to integrate behavioural flows tested and validated in the synthetic environment, on a real electric board (behavioural board), to customize the autonomy of the autonomous systems. This activity would require an implemented and synergistic study with the Company for both the development of the behavioural electronic board and the potential integration of it, contextually, to the communication protocols implemented in the operative system of the robot (ROS – Robotics Operating System). In this context, it could be developed a series of behavioural libraries, to characterize both mission execution and counter-measure, consenting the operative to recreate, in a user-friendly manner, a comprehensive behavioural structure to function for a specific operation.

To summarize, **Figure 2** shows a circular scheme describing the peculiar phases of the development of a RAS capability in a military setting through a reciprocal feedback between a real and simulated world.

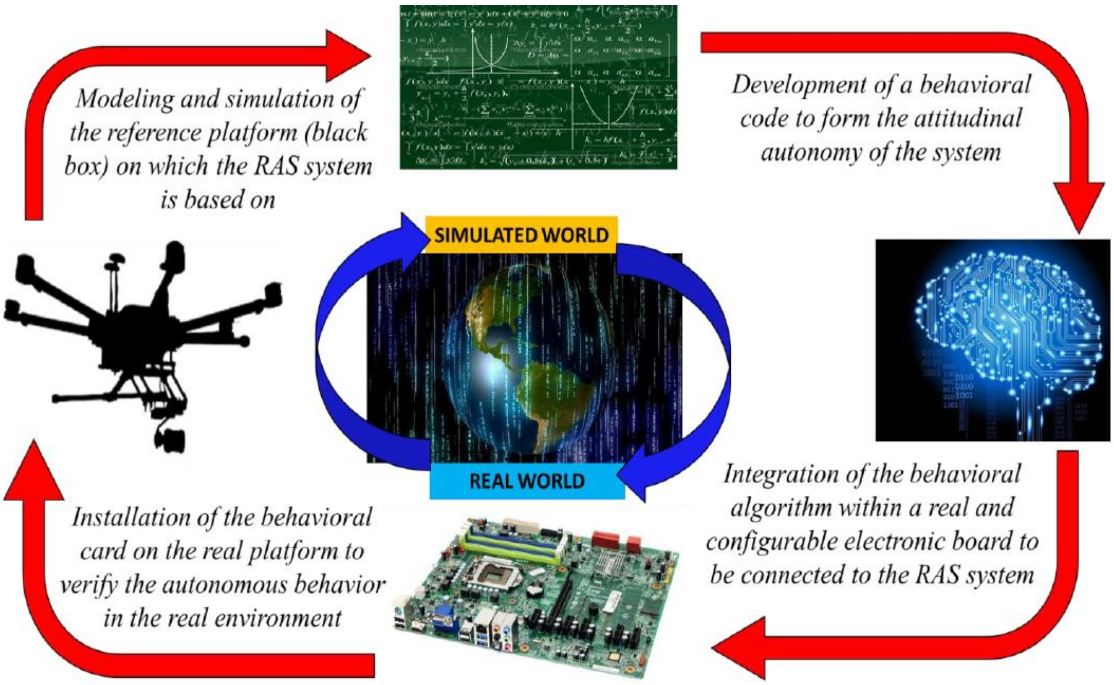

Figure 1. Main phases for the development of a RAS capability with the aid of the Modelling and Simulation tool

The design of an electronic board with integrated behavioural algorithms defined, tested, and validated in a simulated environment, with interconnected modality of autonomous system logic, would be a turning point in the autonomous robotic system setting. The interconnection and interoperability with the logic of a platform relative to sensors and dynamics, would consent for (considering an unmanned platform as example) type COTS (Commercial off the Shelf), with low level of autonomy (Level of Autonomy – LoA = 0) remote piloting and/or waypoint piloting. This assumption is very useful to confer autonomy and increase the relative level of LoA for operative missions. This would allow the creation of a behavioural electronic board, whose code would be tested, verified, and validated in a synthetic environment, operationally usable and adaptable to the scenario, the operative requirements and Tactical Technical Procedures (TTPs). The mentioned board would be able to define a LoA predefined and versatile, for the mission, in an unmanned platform, to cope with complex scenarios and domains, where the threat is dynamically mutable.

2 SWORD RAS – development of a physical/behavioural model for concept and capability development

The next step for the RAS project included the use of a constructive simulator, SWORD, of the MASA company, in which the main idea was to adapt the computational capabilities and to analyze offers by SWORD to the RAS entities used in military operations via the construction of a specific operative vignette for the implementation of a proof of concept.

The peculiarities of the SWORD simulator are the following:

- constructive aggregate simulator;
- analysis tools that consent for the study of different Course of Action (COA) even for wargaming purposes;
- physical database in which it is possible to model the main structural and doctrinal characteristics of the synthetic entity;
- Direct Artificial Intelligence (DAI) tool that defines the logical algorithms in order to implement orders to the simulated entities in relation to the specific conditions around the scenario.

The main elements that characterize RAS systems via M&S activities, which were investigated in the first phases of the project, are the following:

- level of autonomy defined for every mission type;
- writing of behavioural algorithms and codes via the programming language LUA.

Starting with the respective reciprocal characteristics, it is fundamental to understand the idea at the base of the project SWORD RAS, through a simple association between two different fields of application, trying to mix them together, in order to explore the shared advantages.

The main parameters of the entrances in which the project is founded are the following:

- modelling of the physical database;
- modelling of behavioural database;
- external conditions;
- scenario, terrain, and TTPs;
- different LoA and RAS autonomous missions.

The black box analysis, shown in **Figure 3**, represents a significant element that goes into the final purpose of the project, which is explained following specific directions in terms of versatility, mathematic parametrial and multi-factorial analysis.

Figure 3 – diagram of the SWORD RAS project in terms of black box

To summarize, the product is capable to accept as parameters of entrance all the variables present in the physical and behavioral database, in which it is possible to study the exits of the simulations in term of the dynamics of the robotic platforms, sensor networks used (technological aspects), and the manual and autonomous missions implemented inside the robotics system. These aspects need to be associated with the rules of engagement (ROE), TTPs, type of mission, and level of autonomy. Thanks to SWORD's DAI, these physical and behavioural aspects are processed and correlated with the scenario's external factors from a both technical and operative standpoint. The main result of the project SWORD RAS consists of the COA of M multiple simulations realized in parallel to the same scenario, in order to statistically characterize the results in relation to N parametric variables of entry.

These concepts explain the methodology inside the project, as, across the parametric and multi-factorial analysis of the simulated missions, the probabilistic results provide mathematical support in the setting of conceptual and capability RAS development in military operations. The results represent a combination between the behavioural algorithms written in form of behavioral code, the autonomous operations synthesized in the flow diagrams, and the simulation assisted by the electronic calculator, so to be able to contextualize the decisional aspects in relation to the external conditions of the scenario. In the second phase of development of the SWORD RAS project a federated simulation was implemented. In particular, the short-term purpose of this second phase involves the inserting of a three-dimensional visualization in the synthetic environment and of the simulation constructed in the SWORD simulator. For this reason, further simulators in this phase have an aspect of exclusively graphic nature. An example of the federate simulation is shown in **Figure 4**, where the same situation is represented in different simulators that are communicating through the HLA1516e protocol.

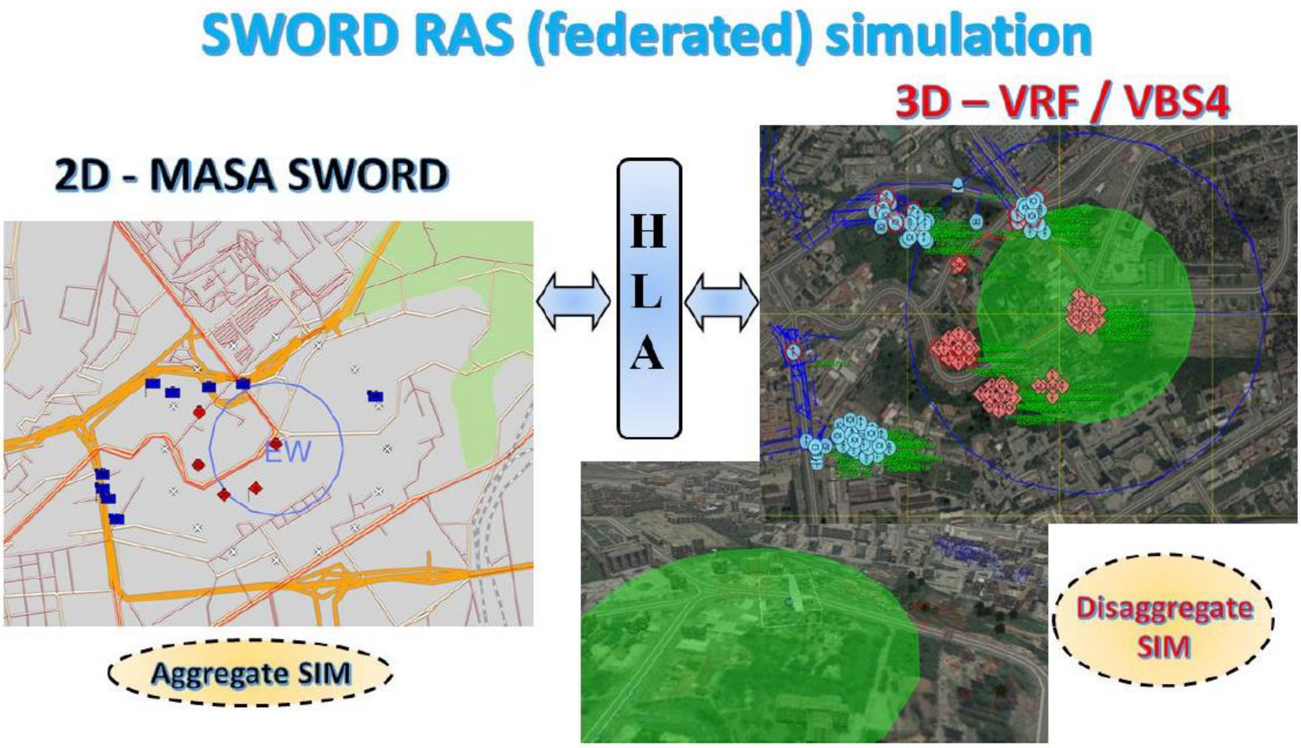

Figure 4 – example of a federated simulation of the SWORS RAS project

The SWORD RAS project represents a proof of concept capable of using the computational strength of the SWORD simulator to develop conceptual and capability development on RAS systems in military operations. The analysis tool allows for to acquiring of graphs for different COAs in a wargaming context, providing mathematical support expressed in specific functions of probability distribution. The analysis process consists of a significant element for the SWORD RAS project, as every result could be improved and correlated to operational and technical elements in a multi-domain context. For example, in addition to the COA the reports that are generated by the simulation, that are shared by the entity and by the formations defined in the synthetic environment, constitute a fundamental set of data that is useful for the understanding of the conceptual and logical processes of the tactical scenario in real time. From the potential applications of the SWORD RAS project, developments can be renewed in capability terms, following a translation of the physical and behavioural model projected in the real world. In particular, the translation of the physical database could have an impact on the characterization of the real system. Similarly, a behavioural translation could be done using the bidirectional process, mentioned for the physical part, to verify the autonomous robotic functions in both real and simulated environments. For this aspect, it is important to study the RAS architecture, focusing on the realization of the autonomous engine and the physical interface of the platform with the surrounding environment. This is important in order to comprehend in which modality and terms to go forward with the behavioural translation to reach an elevated fidelity between the real and simulated worlds. The translation process is very important for the reduction of the gap between operational simulation and reality, to reach the RAS capability development through the SWORD RAS project.

The **Figure 5** shows the architecture that employs M&S tools and expert systems, for future and eventual developments of the SWORD RAS project.

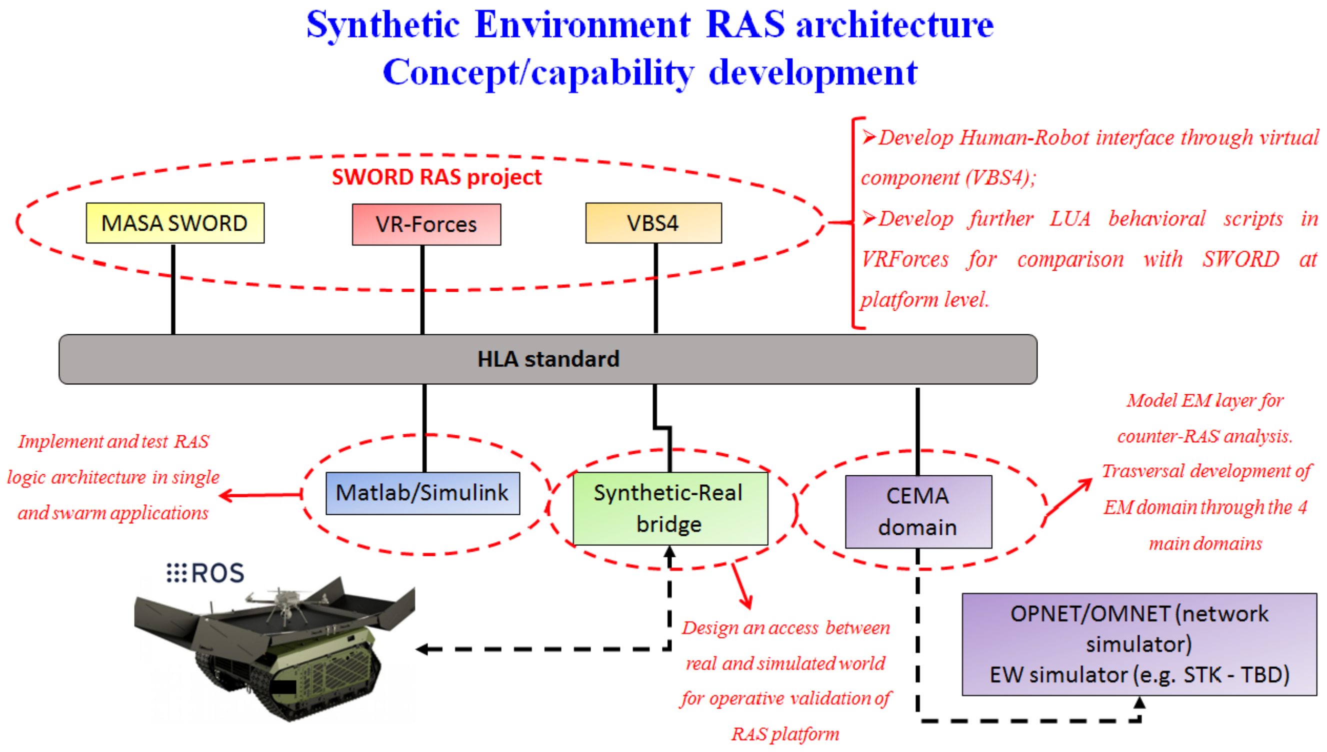

Figure 5 – architecture of RAS synthetic environment for capability development

In this case, considering future developments, the following expert systems were considered:

- Matlab/Simulink for the implementation and verification of the logical RAS architecture in both single and multiple applications (swarms);
- The CEMA domain, using as an example Electronic Warfare simulator to model the electromagnetic layer in counter-RAS applications. The virtualization of an electronic war scenario represents a significant element for the study of the RAS platforms, thanks to the transversal development of an electromagnetic layer through the four fundamental domains at the base of military operations.

In conclusion, a conceptual idea for the potential application of the RAS synthetic environment for the realization of a project in a well-defined field, was brought forward. The idea resides on the development/adaptation of an electronic board, denominated the “LoA implementation board”, through which it could be possible to synthesize an eventual bridge for the interconnection of the synthetic and real worlds. The mentioned electronic board, implementing the circular process described above, would have the main parameters provided by the RAS synthetic environment as entry signals, to allow for them to interact with the Robotics Operating System (ROS) for the management of the autonomous functions of the real platform. Relying on this assertion, the said board would be able to integrate the behavioural algorithms that are developed, analysed, and verified through the simulation, obtaining the platform versatility that allows for the adaptation of different autonomous functions for the mission, the LoA, and the sensors of the robotic system, by communicating with the ROS.

The base concept resides in the transformation of a COTS unmanned platform to a RAS one, through the translation function implemented in the LoA implementation board, to extend the autonomous robotic capabilities to simple commercial platforms.

3 Live Bridge - real-virtual component

The objective of this project is to develop a script, in the programming languages C++ and python, to allow for the synthetic environment to interface with the real platforms, concretizing the significant technical operational worth of modelling and simulation for the capability development of innovative technologies, through the LVC model. In this context, this script could realize the circular conceptual flow on which the entire project in funded on, implementing the ring of connection between the real and synthetic world, with the goal of developing technologically advanced products that would benefit the peculiarity of the mentioned worlds.

The script implemented allows for the applicative to be part of a federation, and therefore part of a distributed simulation, as it is adhering to the HLA standard. The adaptation with the HLA product confers versatility to the project, as it also results to be transposable to other simulations and other used applications.

Regarding the subscription of a real identity in the simulated world, a RAS system could be employed that transmits data regarding position (or eventually another type of data that can be subscribed in HLA) in order to see the attitudinal behaviour of the real system in the simulated environment. This way, in the setting of the employment of M&S tools for the development of autonomous behavioural codes, it could be possible to implement an operational validation of what is modelled and programmed in the simulation phase. This is to comprehend in which way the real system integrates the designed behavioural code with the different and real conditions of the surrounding environment. Through the data collection and analysis process, it would be possible to quantify the gap between the synthetic and real environments, to consent for the eventual and future characterization of developments. This is an example of the ability of this approach. Relatively to the publication of the entities and the relative attributes defined in the simulated environment, one or multiple real systems with alternative simulated systems could be integrated. The explanatory application of this capability could reside in the management of a RAS system swarm, and, by exploiting M&S, the information can be transmitted to the real RAS systems that are interfaced with the synthetic world through this bridge, that can integrate specific behavioural algorithms. This way, for example, transmitting the entity's position with the NMEA message system, it would be possible to command the real RAS systems (for land and/or air) in a swarm modality without the use of any computational components on the platforms. With these characteristics, a strategy integrated in the LoA implementation board to transform the COTS systems to RAS could be implemented, even with low levels of autonomy, for specific military operations.

In this context, it was created a proof of concept that supports and demonstrates the significant passage in the Live capabilities in a synthetic environment for RAS systems in future military operations.

The project, named "Live Bridge", represents a proof of concept of the development of a script that allows for the sharing of information between real and synthetic environments. This step is very important to favour the use of M&S in the setting of RAS capabilities and, in general, for further testing of disruptive technologies through M&S. The proof of concept realized for this project was designed following the following technical guidelines:

- *Versatility, where it is important to constitute the project with a global approach in order to eventually extend the concepts and other applications, such as different themes than RAS;*
- *Bi-directionality, because the bridge of communication needs to be appropriate for both the entry and exiting of the real environment, respecting the most peculiarities defining the synthetic scenario modelled.*

In order to concretize a possible application of the proof of concept for the Live Bridge project, with reference to the circular interconnection between real and simulated world, ***Figure 6*** *describes the entire technical-operational approach for the capability development of RAS capabilities for military operations.*

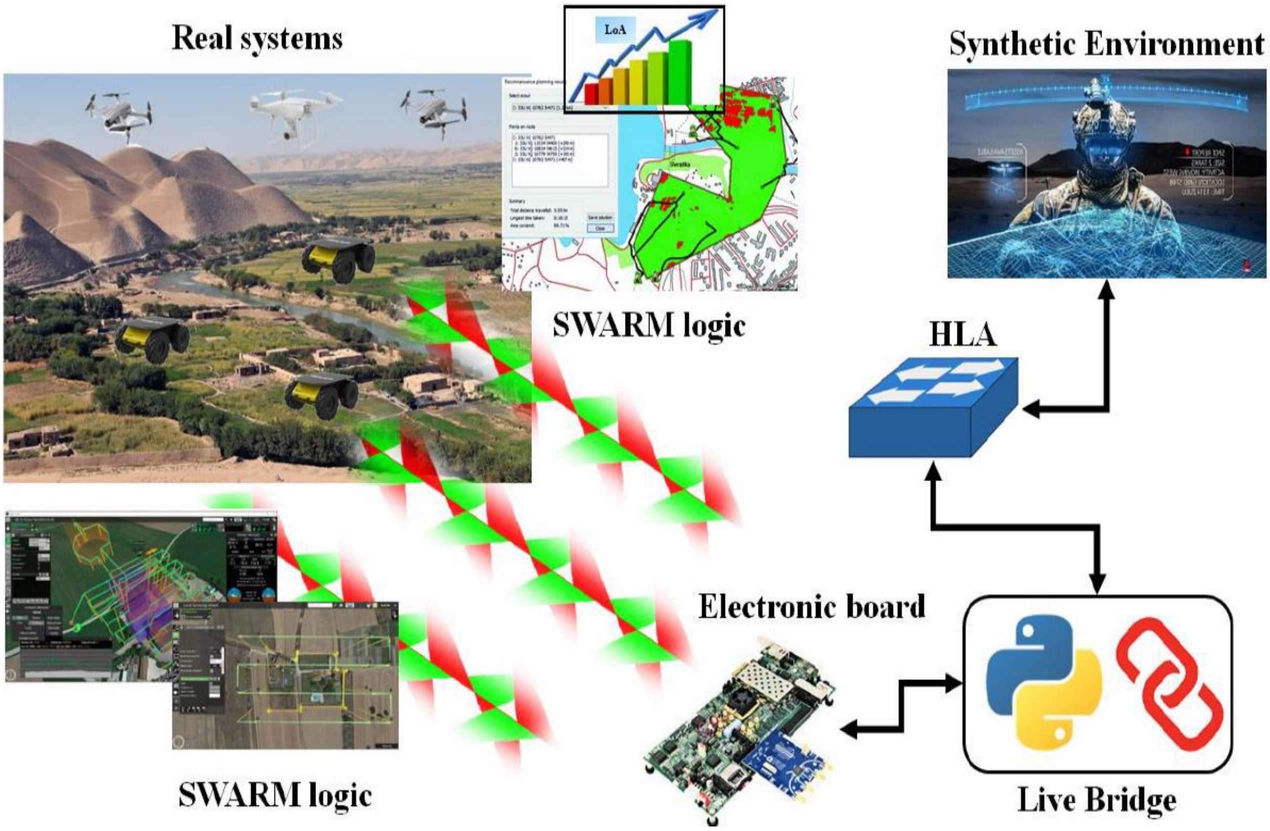

Figure 6 – possible applications of proof of concept in the Live Bridge project setting, with reference to the circular interconnection between real and simulated world in an operational context

The project's versatility and bidirectionality are very important for the different applications that use M&S tools, in the technological experimentation, improving the obtainable results through a combination of the real and synthetic environments. In the RAS experimentation setting, a pragmatic application, focused on the behaviour of the swarms that correspond to a typical and fundamental characteristic of the RAS systems that operate in the military scenery, can be analysed. For instance, the Live Bridge project allows for the streaming of behavioural autonomous codes developed in the synthetic environment, in terms of the main physical attributes of the simulated entities, positions, and movement parameters. These autonomous functions need to be streamed in an unmanned platform, which has to be appropriately configured to continuously accept the information generated by the virtual scenario. The computational autonomous elements centralized in a sole station and managed directly in the synthetic environment, whose effects are projected in a real scenario, reducing the possible gaps between the real and virtual world, favour the situational awareness reached during an operation. The combination of real and synthetic worlds aloe for the testing of different solutions that involve the simulated and non-simulated platforms, exploiting the flexibility offered by the M&S tools and the fidelity of the operational systems that operate in a real multi-domain context characterized by a future operational system.

4 Conclusion

This document has the purpose of highlighting the possible applications of modelling and simulation in important points relevant to the military field, contextual to the tools that are currently present in the NATO M&S COE laboratories, which are of necessary adoption to improve the technical activities of the Centre.

Specifically, this document projects the purpose of this Centre in the capability development and organizational support, paving the way for the structuring, development, and consolidation of a high technical know-how for the technological transformation of NATO. The emphasis on the sectoral issues of the engineering matrix, provides different fields of application for the modelling and simulation tool, not only form an auxiliary and collateral point of view, but also acting as a central cornerstone for the future potential capability developments, by enhancing the use of modelling and simulation in the technological field of the Defence.

In particular, it was given a significant emphasis and central worth of modelling and simulation, demonstrating different applicative declinations in relation to an emerging technology. This technology is represented by the RAS systems for military operations, which are traveling on an outlined technical direction through the projection of different proof of concepts. This way, a multi-perspective view on the issues can be obtained, allowing for a wider view finalized to an eventual and successive analysis of feasibility for the concretization of a highly detailed project. The above-mentioned applicative declinations, with the respective considerations in merit, are described below.

- Development of behavioural codes for simulated RAS entities: federation with different constructive simulators with the implementation of a simulation that included different RAS systems that operated with specific modalities. From a technical point of view, it was demonstrated that the production of behavioural codes in LUA would allow for the conferring of a specific level of autonomy of the robotic platforms, in addition to testing the autonomous behaviour in answer to the conditions of the scenario, in order to validate the behavioural algorithms in a synthetic environment and characterize its performance.
- SWORD RAS project: based on MASA SWORD, through the creation of a specific operational vignette, finalizing the realization of a parameterizable platform given physical and compartmental data with purpose of analysis and wargaming. The obtained results are made of COAs, with a probabilistic trend, that allow for the mathematical quantification and characterization of the conceptual development process in the setting of RAS systems used in military operations. The development of this project is made up of the inserting of other simulators to allow to obtain up to a three-dimensional view, other than the fact that it confers the system a virtual and constructive component. The virtual component consists of the training of a real operator for the completion of a specific mission with the RAS systems that provide the desired COA, following an analysis and modelling process in the constructive environment. This virtual component could reach a higher value on training following the development of a human-robot interface to consent the eventual operator to have interactions with the simulated robot.
- Live Bridge: real-synthetic component, constituent in the realization of a script able to interface with HLA with a simulated environment, realizing a bidirectional door of communication to implement the Live component in the system, following the LVC model. The entry communication would consent for the publication of information about the real environment in the synthetic one, in order to contextualize in an appropriate manner and with the most fidelity the results obtained in the simulation. In addition, the exiting communication would consent for the retrieving of the synthetic entity's attributes to use them in a real scenario and systems, for example, obtaining a RAS swarm logic. The swarm of robotic systems would be completely piloted by a central activity, on logic and interactions designed exclusively inside the synthetic environment.
- Mathematical modelling through Matlab/Simulink: mathematical modelling allows for the entire architecture to offer different levels of modelling. Indeed, with a mathematical model describing the platform, the sensors and/or functional elements of the autonomous computational architecture of the system, it would be possible to obtain a fundamental complementarity in the M&S setting for the RAS systems. In this context, the results obtained from the modelling of the RAS system and the interaction with the synthetic environment would allow for the fidelity required for the capability development to grow, consolidating in the majority the circular process expected between the real and simulated world.
- CEMA activity: the modelling of a CEMA layer represents a fundamental point in the process of technological innovation of RAS systems in military operations. In particular, the countermeasures that exploit the electromagnetic spectrum provide an added value with higher technical-operational value. The modelling of the electromagnetic environment, aimed at the technical study finalized to the analysis of the operational impact,

would allow the characterization of the fields of action that contextualize in a complete manner the missions with autonomous platforms.

The presented project is mainly based on the different proofs of concept, preparatory for conceptual and capability development. From an executive point of view, relative to the autonomous robotic systems in military operations, the integration of innovative technologies characterized by a significant strategic value is considered significant, for example: the use of 5G communications, arms with direct energy, and devices that operate based on the principles of quantum information. The quantum mechanics offers more potential in respect to operational devices with classic technology, in the field of encryption and communications, artificial intelligence, and in sensor capabilities (such as quantum radar). Furthermore, the modelling of EM (Electromagnetic) concepts in a synthetic environment with an EW (Electronic Warfare) scope (M&S EW) would allow for the characterization of a layer that assumes the progressive technical-operational value in the future military operations, consenting, for example, the design and simulation of the electromagnetic countermeasures in a complex and heterogeneous spectrum, in the optics of both electromagnetic interoperability, and multi-factorial analysis in the context of electronic warfare.

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Wargame Design Capability

Maj Melissa Sawyer
United States Space Force Head of the Wargaming Branch
NATO Joint Warfare Centre

"Wargames are about understanding, not knowledge. They are about ideas, not facts. They are about people, not technology. They do not help us make better decisions through their outcomes. Rather, they help us make better decisions by sharpening and refining the stories we tell ourselves."

Dr ED McGrady

The Joint Warfare Centre's (JWC) wargame design capability was born of innovation to accelerate Alliance learning and alleviate increasing exercise complexity. Over the last two years, the JWC heard a growing demand signal from our customers for quick turn training events to address emerging concepts and complex problems that are not currently tackled in our hallmark command post exercises (CPXs). In addition to the demand signal for more agile training methods, the JWC recognized an increase in exercise complexity due to additional training audiences and a corresponding increase in training objectives.

During the JWC's Fit for Future and Vision 2025 workshops in late 2019 and early 2020, staff formed a plan to partially address both opportunities of accelerating Alliance learning and reducing exercise complexity using wargames. The plan comprised four lines of effort (internal training, planning and design process documentation, external engagement, and a proof-of-concept wargame) and advanced the JWC's wargame design project to initial operational capability (IOC) by February 2021.

The first step towards developing a wargame design capability was training a core team of staff on the basics of wargaming. Staff members with established CPX expertise in the functional areas of project management, warfare development, analysis, scenario, and modeling and simulation met weekly to discuss how their respective functional area would contribute to the JWC's wargame design capability. Underpinning these conversations was a set of landmark wargaming textbooks that aided in applying the team's CPX expertise to wargaming.

In addition to reading about and discussing the basics of wargaming, the team coordinated a more tangible training event. A commercially available matrix wargame provided the core team, and many other JWC staff members, the opportunity they were looking for to test out this newly acquired wargaming knowledge. The team captured observations from their internal running of the game in the JWC Observation Reporting Tool (JORT) and fed those observations into the next step of building the capability: documenting the planning and design process.

In July 2020, the wargaming core planning team held two two-day Wargaming Standing Operating Instruction (SOI) writing workshops. Using the JWC's "Planning of Exercises Standing Operating Procedure 800" (SOP 800) as a template, each team member authored their respective functional area's SOI content, and presented their content to the broader team to ensure consistency.

Debates during these workshops forged the team's shared understanding of what a wargame means to the JWC, and the Centre's wargame delivery level of ambition. By the end of the workshops, the team had a draft "Wargaming SOI" to be iterated upon using observations from the design and delivery of the JWC's proof-of-concept wargame.

During this period of internal training and SOI-drafting, the JWC was awaiting responses to Commander JWC, Rear Admiral Jan C. Kaack's call for wargame topics from interested NATO Centres of Excellence (CoEs). Of the responses received, the wargaming core planning team chose the Civil-Military Cooperation (CIMIC) CoE's "*Resilience through Civil Preparedness*" topic as the focus for the JWC's proof-of-concept wargame.

Coordination with the CIMIC CoE began in earnest in late July 2020, with initial discussions dedicated to understanding and refining the CIMIC CoE's wargame objective and assumptions. The JWC and CIMIC CoE collaboratively named the wargame "WISE AEGIS". The first word starting with "*W*" identifies the event as a wargame, with "wise" specifically chosen for the game's intent to be educational. The second word, "*Aegis*", refers to the Greek goddess Athena's magical cloak: a defensive shield that is soft, yet strong, symbolizing the game's topic of civil-military interaction.

Mirroring NATO's exercise planning process, the team held an initial planning conference (IPC) in September 2020. The IPC codified the wargame's objective, overarching parameters, and deliverables timeline in a game specification (GAMESPEC). Concurrent with these activities, the JWC hired the U.S. Naval Postgraduate School's (NPS) mobile training team to deliver their "Basic and Advanced Analytical Wargaming" courses at the JWC. The courses reinforced the wargaming core planning team's self-study, expanded wargaming knowledge to

The JWC's wargame design capability can have the same, if not even more, impact on myriad other complex problems such as targeting and logistics, and operationalization of new concepts such as the Deterrence and Defence of the Euro-Atlantic Area (DDA).

SCAN ME WATCH the Video

"Our goal is to establish a wargame capability for NATO by combining the Joint Warfare Centre's unique exercise expertise with exciting new professional development opportunities in order to build the necessary skills, knowledge, and competence within the organization."
— Rear Admiral Jan C. Kaack

additional JWC staff members, and progressed the design of WISE AEGIS.

The COVID-19 pandemic interfered with initial plans, but those involved persevered, and the courses were delivered in person at the JWC in October 2020. Select JWC staff members also earned a certificate in wargaming from the U.S. Military Operations Research Society (MORS) to deepen their wargame design expertise. The NPS instructors, U.S. Army Colonel (Ret.) Jeff Appleget and U.S. Army Colonel (Ret.) Robert Burks, seamlessly integrated wargame design methodology lectures with practical exercises to advance the design of WISE AEGIS. The 20-student course, split into two syndicates, produced two prototype games for CIMIC CoE down-selection. The CIMIC CoE found value in both games, so both were developed to completion for delivery in February 2021.

Following the NPS course, and given the global COVID-19 situation, the wargaming core planning team converted the in-person WISE AEGIS blended matrix/board-format wargames into virtual, distributed wargames. Critical to the games' success were two rounds of JWC-internal playtesting, allowing fresh eyes and constructive criticism from the JWC's Transformation Delivery Division to help the game designers spot and fix flaws before execution with the customer.

Also imperative to the games' success were the extensive rehearsals conducted with game control (GAMECON) and all wargame players a week before game execution. Potentially derailing issues such as microphone/speaker feedback loops and player unfamiliarity with the games were averted thanks to the rehearsals. Execution saw 65 people participate via a virtual platform from 23 organizations across 12 NATO Nations, and included players from NATO HQ, the NATO Command Structure, the CIMIC CoE, industry, a NATO national joint headquarters, and a NATO nation's centre for security.

Figure – The NATO Civil-Military Cooperation Centre of Excellence used the JWC's wargame at their "Resilience Through Civil Preparedness" course. The virtually delivered course is a huge return on the JWC's "training-the-trainers" approach in delivering a wargame. Photo by CCOE.

JWC Wargaming Branch

The game's successful completion checked off the wargame design capability's final IOC criteria, so Rear Admiral Kaack declared IOC on February 12, 2021. To institutionalize wargame design as an enduring capability of the Centre, on March 19, 2021, the Commander created a five-person Wargaming Branch and a 50-person wargaming cadre. The Wargaming Branch will lead the design, development, and delivery of JWC's wargames and leverage the functional expertise of the wargaming cadre to ensure seamless integration of wargames into CPXs. In addition to creating a Wargaming Branch and cadre, Rear Admiral Kaack also approved a DOTMLPFI (doctrine, organization, training, materiel, leadership, personnel, facilities, and interoperability) development plan that expanded upon and added more details to the original four lines of effort that brought the capability to IOC. The development plan, now in execution, culminates in a fully operational wargame design capability by the second quarter of 2022.

In the capability's current IOC state, we are already seeing how the benefits of wargame reuse and cost efficiency support our overall goal to accelerate Alliance learning and alleviate increasing exercise complexity. The CIMIC CoE, for example, used WISE AEGIS in their "Resilience Through Civil Preparedness" (RtCP) Course, and plans to use a modified version in their NATO CIMIC and Civil-Military Interaction Higher Command Course. Additionally, an RtCP student from a component command has since brought the game back to their headquarters for further use. Already, one wargame is seeing at least three uses to teach CIMIC principles in an engaging, thought-provoking way.

Wargame reusability emphasizes the capability's cost efficiency. Eleven staff members working part-time on WISE AEGIS created a wargame in less than six months that reached more than 100 participants and observers within a month of its release. That is at least 100 more people who now better understand how an operational-level command can use civil-military interaction to enhance RtCP.

The JWC's wargame design capability can have the same, if not even more, impact on myriad other complex problems such as targeting and logistics, and operationalization of new concepts such as the Deterrence and Defence of the Euro-Atlantic Area (DDA). With the JWC's Wargaming Branch and wargaming cadre, the Centre will deliver bespoke training and problem exploration wargames at the speed of relevance and work with exercise planning teams to design wargames that reduce exercise complexity while increasing training value. The JWC's wargame design capability is taskable now through the JWC's Commander and the Centre's wargaming cadre is thrilled to offer this capability to the Alliance's organizations and Nations.☐

A full description of the games and their analysis can be found in the WISE AEGIS Final Report, which is available to interested parties by contacting

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Deep Self-optimizing Artificial Intelligence for Tactical Analysis, Training and Optimization

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Abstract

The increasing complexity of modern multi-domain conflicts has made their tactical and strategic understanding and the identification of appropriate courses of action challenging endeavors. Modelling and simulation as part of concept development and experimentation (CD&E) provide new insight at higher speed and lower cost than what physical maneuvers can achieve. Amongst other, human-machine teaming through computer games provides a powerful means of simulating defense scenarios at various abstraction levels. However, conventional human-machine interaction is time-consuming and restricted to pre-designed scenarios, e.g., in terms of pre-programmed conditional computer actions. If one side of the game could be taken by Artificial Intelligence, this would increase the diversity of explored courses of actions and thus lead to a more robust and comprehensive analysis. If the AI plays both sides, this would allow employing the Data Farming methodology and thus creating and analyzing a database of a very large number of played games. To this goal, we employ combined Reinforcement Learning and Search algorithms, which have demonstrated super-human performance in various complex planning problems. Such Artificial Intelligence systems avoid the reliance on human experience and predictions by learning tactics and strategy through self-optimization in a large number of realistic scenarios. In this contribution, we present the benefits and challenges of applying a Neural-Network-based Monte Carlo Tree Search algorithm for strategic planning and training in air-defense scenarios and virtual war-gaming with systems that are available currently or potentially in the future to the Swiss Armed Forces.

1 Introduction

Today, wargaming is a widely applied and accepted tool within the military domain for planning, training and decision-making. However, traditional wargaming, where military planners, operators and decision makers play against Red Team operators, faces limitations [1]. Wargames are driven by player decisions and are therefore not reproducible. Objective tracking of cause and effect is difficult, and outcomes often depend on the subjective assessments of human players. Usually, Red Team operators rely upon long established techniques, tactics and procedures leading to over-constrained Courses of Action (CoA). Finally, the number of CoAs that can be explored by human operators is limited, both by the availability of financial and human resources. This is even more true given the complexity of continuous-time decision making and the large numbers of available options (high branching factors) that characterize real-world scenarios. In practice this results in a relatively small number of explored scenarios and a lack of strategic diversity in CoAs exploration, leading to biased and potentially vulnerable decision-making.

Recent developments in the Artificial Intelligence (AI) area and in particular Reinforcement Learning (RL), have demonstrated the ability of artificial agents to master commercial real-time strategy (RTS) video games of increasing complexity, reaching super-human performance in games such as StarCraft [2]. Artificial agents have also proven super-human tactical and strategic capabilities in complex games such as Chess and Go [3]. Typically, modern RL systems learn 'tabula rasa', i.e., without relying on human experience, by exploring complex decision-spaces in a large number of scenarios and subsequent self-optimization. This avoids the bias towards human experience and perception in learning and leads to more robust, stronger, and non-emotional decisions in execution. While the learning process of AI systems often involves significant computational effort, their speed in execution is fast, often outperforming the 'discussion-based' human decision process.

In this work, we investigate AI systems, in particular Neural-Network-based Monte Carlo Tree Search algorithms, to support planning, training and decision-making in the field of Ground-Based Air Defence (GBAD). We apply the AI to the commercial of the shelf (COTS) wargame "Command: Modern Operations" (CMO) to explore complex decision-spaces, and to generate surprising new Red Force CoAs. This will challenge the preconception of Blue Force operators and stimulate the development of new techniques, tactics, and concepts.

2 Methods

Two main software components are involved in the application described above. First, there is the model with rules and physical constraints of the scenario to be simulated (the so-called simulator), and second, an AI algorithm that controls one or both players in the conflict represented by the model. Both components and their integration are described in this section. In the current scenarios, one side of the game is played by an AI agent, while the other is controlled by the game engine itself, through pre-scripted, conditional actions. Specifically, the AI controls the attacking red fighter jet while the game engine controls the blue air defense batteries.

2.1 Model

The use of commercial over-the-shelf (COTS) games as simulation engines has a number of advantages: low cost, large user-base, high fidelity and good support to name just a few. Also, the gaming industry has been a driver for the development of realistic warfare scenarios, respective visualizations, and tailor-made hardware. Two central requirements for a model to be controlled by an external AI are:

1. faster than real-time simulations, this in turn requires in general to run the simulation without graphics;

2. interface to control and assess the state of the game externally.

The game “Command: Modern Operations” (CMO) fulfils these requirements in its professional version (Command Professional Edition) and additionally covers the domain of interest, namely air defense. It is a real-time strategy game mainly for air and sea combat that features a comprehensive and realistic database of past, current and future weapon systems.

Figure 1 – User interface of Command: Modern Operations [7]

It comes with an API that allows interaction with the running simulation in batch mode, i.e., without graphics. In order to make the game more amendable to the AI, we introduced a turn-based mode for the real-time game. The game is paused and the AI can assess the scenario and select an action. Subsequently, the action is executed and the game is simulated for a given time window, here 10 seconds simulation time.

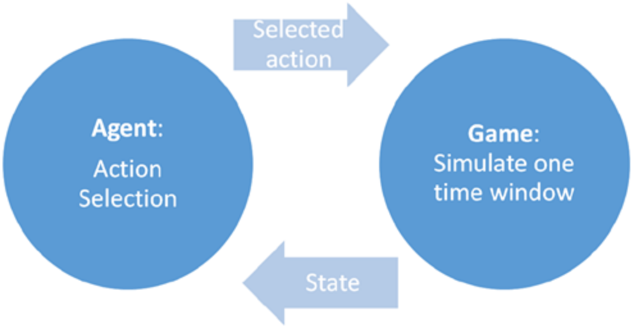

Figure 2 – Turn-based game mode of Command: Modern Operations

In the design mode, one has the possibility to create a scenario with pre-defined or custom assets. In game mode, the simulation is then executed with the actions from either the players or the external AI.

2.2 AI

For complex game search problems, such as the CMO scenarios, the direct computation of optimal policies is intractable. The development of suitable approximation techniques has been an active area of research for many years leading to striking AI systems that outperform humans and classical tree search algorithms in strategic games such as Chess and Go [3]. At the core of the AI lies a sophisticated neural network-based Monte Carlo Tree Search algorithm (neural MCTS), whose performance is the result of a combination of techniques from diverse areas including Reinforcement Learning, Monte Carlo simulations and Deep Neural Networks. Traditionally search algorithms (such as alpha-beta search) are employed to study game play, but the search tree grows exponentially with its depth leading to large computational effort even for simple games. The tree's terminal nodes must be evaluated by a tailor-made valuation function, whose design involves significant human expertise. On the other hand, the choice of actions in a (Markovian) game can be viewed as a planning problem, with an agent whose goal is to win, or, in other words, to maximize the total reward over the planning horizon. Such planning problems are footed on the theory of Markov decision processes [4]. The research area concerned with their solution has been commonly called Reinforcement Learning (RL) in recent years. In RL the Value/Policy iteration algorithms proceed by performing repeated Bellman updates over the state space and are guaranteed to yield the optimal policy if sufficient resources are granted. However, even for planning problems of moderate complexity the required resources tend to be immense because each Bellman update involves the entire state space. An important idea to improve the performance is to rely on Monte Carlo simulations to estimate state values [5]. In brief each state is evaluated by trying every possible action a certain number of times, and recursively, from each generated state every possible action the same number of times, too, until the depth of the planning horizon is reached [6]. Again, this yields the optimal course of actions in theory but in practice the width and depth of the Monte Carlo simulations are such that a near optimal solution becomes elusive. The key idea behind MCTS is to combine the iterative algorithms from RL with (the more traditional) tree search techniques [7]. Thus, instead of relying on 'brute force Monte Carlo' for state valuation, a problem-specific, restricted and asymmetric decision tree is built. The growth of the decision tree is controlled by a dedicated tree policy, whose purpose it is to trade-off the creation of new branches versus the execution of existing promising lines. The missing piece to engineer a world-champion AI are deep neural networks. The MCTS design is enhanced by deep neural networks [8] to guide the construction of the decision tree and to provide accurate evaluation of leaf-nodes. At the core of the neural MCTS algorithm lies an 'expert iteration' scheme, where the MCTS search and the neural networks mutually improve each other in an iterative process. In each iteration an instance of MCTS (the expert) delivers a list of strong actions and a neural network (the apprentice) is trained via supervised learning to imitate the MCTS tree policy. In the next iteration, the trained neural network, in turn, is used to bias the MCTS' tree construction towards stronger actions. The purpose of the expert is to accurately determine good actions. The purpose of the apprentice is to generalize those actions across states and to provide faster access to expert advice. Specifically, the apprentice policy π is trained on tree-policy targets by minimizing cross-entropy loss at state s

$$Loss_{TreePolicy} = -\sum_{a \in actions} \frac{n(a)}{n} log\left(\pi^{A}(a|s)\right).$$

Here, n(a) is the number of times action a has been chosen so far and n is the total number of executed actions. The value network reduces search depth and avoids inaccurate rollout-based value estimation. It is trained to minimize the mean-squared error to the MCTS valuation z of the state

$$Loss_{Value} = -\left(z - V^A(s)\right)^2.$$

In turn the apprentice improves the expert by guiding tree search towards stronger actions. For this the standard MCTS tree policy (UCB1) is enhanced with an extra term

$$NUCB1(a) = UCB1(a) + w\frac{\pi^A(a|s)}{n(a)+1},$$

where a hyper-parameter w weights the contributions of standard MCTS tree policy (UCB1) and the neural network. Neural MCTS branch selection proceeds by choosing the action a that maximizes NUCB1. To regularize value prediction and accelerate tree policy and valuation function are simultaneously covered by a multitask network with separate outputs. The loss for this network is the sum of losses from value and tree policy networks.

2.1.1 Training process

To achieve faster learning and higher stability the RL agent is pre-trained before operating on the game CMO directly. In order to optimize the training process, a surrogate model was written in the language (Python) that was used for the AI algorithms. This allowed the agents to be pre-trained from scratch, later to be refined by training on the full game engine. Thus, the process involves the training on a reduced but faster simulator, then transferring the pretrained agent to the CMO simulator for fine-tuning. This way the data-intensive (and therefore slow) initialization of the RL process can be handled efficiently, while there is no reduction in the agent's performance due to training in a restricted setting.

3 Scenario

The reason armasuisse Science and Technology is interested in this technology, is the application to air defense training, concept development and experimentation (CD&E) as well as procurement projects. The main assets employed in the warfare scenarios are fighter jets, radars, and air defense missile systems. Ideally, an intelligent agent would be capable of identifying and executing a close-to-optimal strategy for all assets of one side simultaneously. Due to the complexity of fully realistic scenarios, developing and training of such an agent is beyond the goals of the current project stage. Instead, the aim is a feasibility study with reduced scenarios, where the RL agent controls a single asset. This scenario will be extended in a later stage of the project. The simple test scenarios are characterized in the above figure 2-1 and the following table 3-1:

	Red Side	**Blue Side**
Assets	1 Fighter Jet	1 SAM Battery (Radar, missile system)
Mission	Penetrate blue Zurich airspace (yellow)	Defend blue Zurich airspace (yellow)
Red Scoring	+1 for attacker mission success -1 for loss of aircraft	-1 for defender mission success +1 for attacker mission success

Table 1. Scenario description

4 Results

The AI controlling red aircraft learns quickly that flying the direct path from its takeoff to the target will make it visible to the blue radar and therefore vulnerable to blue air defense. It thus chooses a more northern route to avoid the radar cone. In the following, we will work out what went well and where we see the challenges and bottlenecks for the transition to more interesting and complex scenarios.

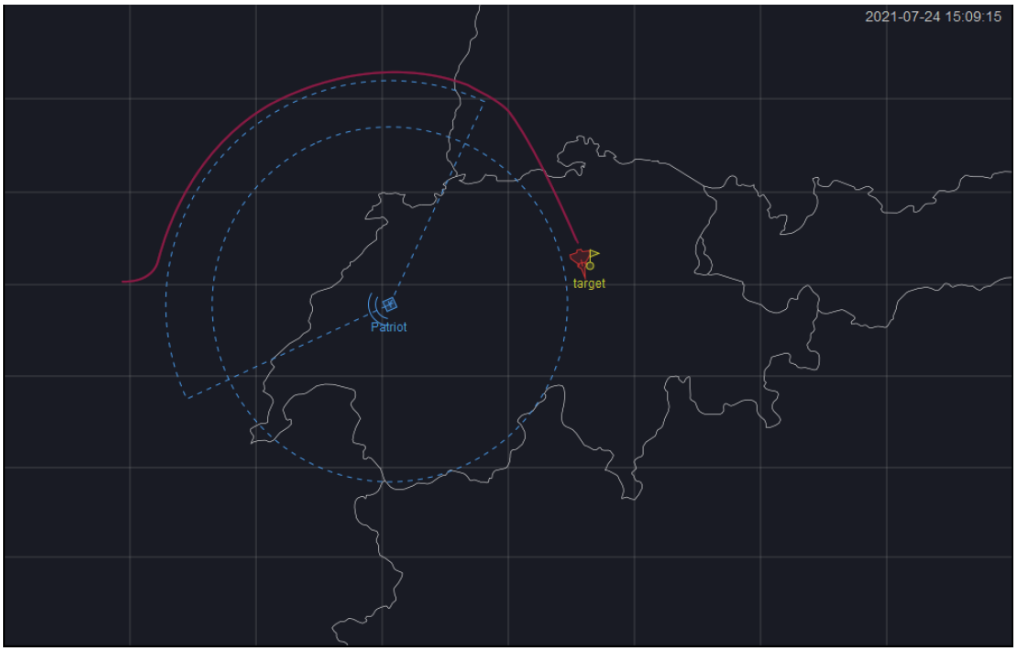

Fig. 4. Example trajectory of trained red agent around the range of the blue air defense system.

4.0.1 COTS Game as simulation engine and its interface

The use of a commercial over-the-shelf computer (COTS) games has a positive impact on the outcome for the reasons mentioned above. Additionally, the separation of AI, simulation engine and analytics tools make the application design more flexible and re-use of components possible. In particular, this approach avoids a large black-box simulation engine, where insight and extensibility are limited.

4.0.2 Application of neural MCTS to CMO scenarios

In all investigated scenarios the outlined training procedure led to neural MCTS finding the maximal theoretical reward after only a short number of learning cycles (5 neural training cycles, each based on 500 episodes and 100 MCTS samples per search step for all investigated scenarios). While this is somewhat expected given the relatively low complexity of the combat scenario and the proven ability of neural MCTS to solve sophisticated strategic problems, the presented work provides proof of concept that the practical implementation in the CMO context is successful. Connecting neural MCTS to CMO requires a dedicated API with fast access. In our experiments we have observed that access via the existing Lua API is too slow for MCTS to guide the behavior of CMO. To overcome this issue a dedicated surrogate simulator has been developed, which provides fast access in a simplified setting. The pretrained MCTS agents are subsequently handed to the full CMO setting for fine-tuning. As a result, we observe solidly increasing rewards on the simulator and the trained agent can be transferred to CMO successfully.

5. Conclusions and outlook

Our results provide proof of concept of the application of RL and search techniques in the context of COTS wargames. In forthcoming research, the complexity of war game scenarios will be increased successively. The more complex setting is reflected by adaptations in the neural MCTS architecture. While simple linear, feed-forward networks are sufficient for the basic scenarios, we plan a deep convolutional architecture for the more complex setting. The additional computational burden of the complex scenarios is covered by code parallelization and cluster computing. We expect that MCTS will also be successful in complex scenarios as neural MCTS algorithms proved their superior performance in strategy games like Chess and Go. Overall, the value of an independent and innovative simulation application for training as well as CD&E seems larger than the prize to overcome the challenges in developing it.

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Blessings of AI and ANNs?

Markus Reisner

Artificial Intelligence (AI) can be defined as process which enables machines and robots to imitate human behaviour. There are two subcategories, machine learning and deep learning. Machine learning uses computerized statistical methods to enable machines to improve with experience. Deep learning tries to enhance computation by using multi-layer artificial neural networks, so called ANNs. The aim of artificial intelligence is to transfer from „frozen software" (which need regular updates) to „evolving sofware" (which is updating itself). According to the current state of technological development, artificial intelligence is defined primarily in the analysis of large amounts of data. It is therefore not yet referred to as a "technical singularity", i.e. an "intelligent" mechanical entity, but rather as the creative management of Big Data. This is primarily performed for the purpose to assist or enhance human decision making. And this function is not only of essential importance in social networks but also in warfare. Here, data preparation is of special significance. [1]

The end of the 20th century brought a major change in the traditional pattern of conflict that had been familiar until then. Today it seems that wars between states fought by conventional means are increasingly becoming the exception. However, the beginning of the 21st century brings further developments with it, the effects of which are much more decisive and the full extent of which cannot yet be assessed. Digitization, the development of potent information technologies and artificial intelligence created the conditions for a revolution in civil domains and warfare with the decisive step of increasing automation and autonomization of military weapons systems. Today's international armed forces are equipped with modern weapon systems that make it possible to have a lethal effect at any time, anywhere in the world and without endangering one's own personnel. The boundaries of space and time have thus been greatly altered for military operations. The previously known parameters for military operational thinking, i.e. force, space, time and information, are beginning to change as a result, and new possibilities also arise at the strategic level with regard to the use of means. [2]

In contrast to the nuclear missile with its devastating area effect, the military now has a "family" of unmanned weapon carriers and weapon systems at its disposal, which anticipate an unprecedented precision in the use of weapons in the air, on land and on water. Building on this, the man-made possibility of using unmanned, semi-autonomous, robot-like weapon systems was created: The remote-controlled deployment of airborne, unmanned, designated reconnaissance systems and their increasing use for the transfer and deployment of lethal weapons open up previously unexpected manoeuvres for modern armed forces. At present, the human operator still controls the use of such systems, but science and technology are in the process of taking the next technological development step and creating the possibility of excluding the (remote) operator. This - decisive - circumstance must be considered more closely, taking into account its possible consequences. [3]

Human control of manned and unmanned weapons systems is exercised via network structures in cyberspace. If an opponent succeeds in controlling and penetrating his own networks, optional attack or defense strategies have to be developed. Due to limited communication, these strategies can only be based on a higher degree of autonomy of software and hardware. In the domain of cyber, the development of semi-autonomous programs is already being actively pursued. These are intended to be used to carry out various Computer Network Operations (CNO). However, partial autonomy seems to be only an intermediate goal here. One example is the development of a program called MonsterMind for the US National Security Agency (NSA). The purpose of the program is to detect and neutralize possible cyber attacks on the USA at an early stage. Due to the high speed with which such operations are performed, the goal obviously is to use the program in a fully autonomous mode. The case of a fully autonomous software in combination with a Lethal Autonomus Weapon System (LAWS) could indeed change modern warfare decisively: The decision about the right to life or physical integrity would be taken out

[1] Vgl. Markus Reisner: Robotic Wars, Norderstedt 2018, 244ff und 291ff.

[2] Vgl. David Lonsdale: Strategy, in: David Jordan, John D. Kiras (Hrsg.): Understanding Modern Warfare, New York 2008, 16ff.

[3] Paul Scharre: Robotic on the Battlefield – Part II: The Coming Swarm, online unter: http://www.cnas.org/sites/default/files/publications-pdf/CNAS_The Coming Swarm_Scharre.pdf (23. Dezember 2015).

of the hands of the human being, he would be degraded to a mere spectator. [4]

The leap to the development of a fully autonomous robot does not necessarily come first from the military, civil research is equally involved in future applications. Fully autonomous systems have a number of advantages. First and foremost is the fact that humans need time to go through their decision cycle (Observe, Orientate, Decide and Act, OODA loop). This time can be largely marginalized by a fully autonomous system. Unmanned reconnaissance and weapon systems in which humans are in or on the loop have the disadvantage that the necessary up- and downlink communication between unmanned system and control station supposedly takes too much time. to ensure effective defense. The automatic PHALANX or AEGIS defense system used in many of the world's war fleets is such an example. In such a system, man is reduced to a purely observer role. He can and should only intervene when necessary. In fact, there are already a number of systems that have a high degree of automation and autonomy. [5]

In the longer term, it can be assumed that ultimately fully autonomous reconnaissance and weapons systems using low levels of artificial intelligence will be able to independently resolve situations of moderate complexity (e.g., unarmed reconnaissance or armed patrols in a defined and designated area) at the end of a corresponding development process. The current development of such systems, their advantages and disadvantages, must be clearly addressed by military and political decision-makers to a broad public. Only through appropriate transparency can it be avoided that any unwanted developments gain a foothold. Not only politics, but also military and civil research must be held accountable for this. However, given a competitive world and against the scarcity of international regulations in the field, it is a fact that the armament efforts of state actors are currently aimed at overcoming the prevailing stalemate of "nuclear deterrence" and "information superiority" through AI and ANNs. [6]

A fully autonomous robot equipped with artificial intelligence, on the other hand, would be able to independently collect information about its environment using sensors. This information is processed by high-performance processors and forms the basis for a decision, which is then implemented by means of installed components (such as movement mechanisms or weapons). By increasing its experience, the robot is increasingly able to optimize itself. The effectiveness of its actions is constantly increasing. A possible use of weapons no longer remains proportional, but becomes more effective. The robot's software works based on purely mathematical calculations and negates moral or ethical considerations. The result is a "fighting machine" (or killer robot) to which every inhibition is foreign and which can only be stopped by technical failure or destruction or (in the best case) command from outside. [7]

This means, therefore, that no matter what degree of autonomy a reconnaissance and weapon system on land, in water, in the air or elsewhere will achieve in the future, the question of human responsibility in the use of such developments must always be asked. A violation of international law can be caused by the wrong actions of man in or on the loop. In the case of a possible fully autonomous system (artificial intelligence, off the loop), however, this could either have been programmed in violation of international law from the outset, or a technical defect could be the trigger for misguided action. Countries developing such items are therefore called upon to take the observance of international legal norms seriously in the future as well, or to provide for the exercise of human control in software developments. In the development of future fully autonomous reconnaissance and weapon systems, it is necessary to impose certain basic ethical requirements on the expected technological developments.

To sum up, any programming of the software of a future fully autonomous weapon system should be designed in such a way that humans have the possibility to intervene at any time when an autonomous system is in use. Furthermore, it must be ensured that the programming

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[7] Vgl. Markus Reisner: Robotic Wars, Norderstedt 2018, 291ff.

of the software already includes appropriate control mechanisms. [8] In this ambiguous endeavour - on the one hand to be in mission for defense, on the other for support of societal organisation and democratic decision-making by AI means – each and every action has this dual heading of good and bad, the twinned antipodes of all innovation.

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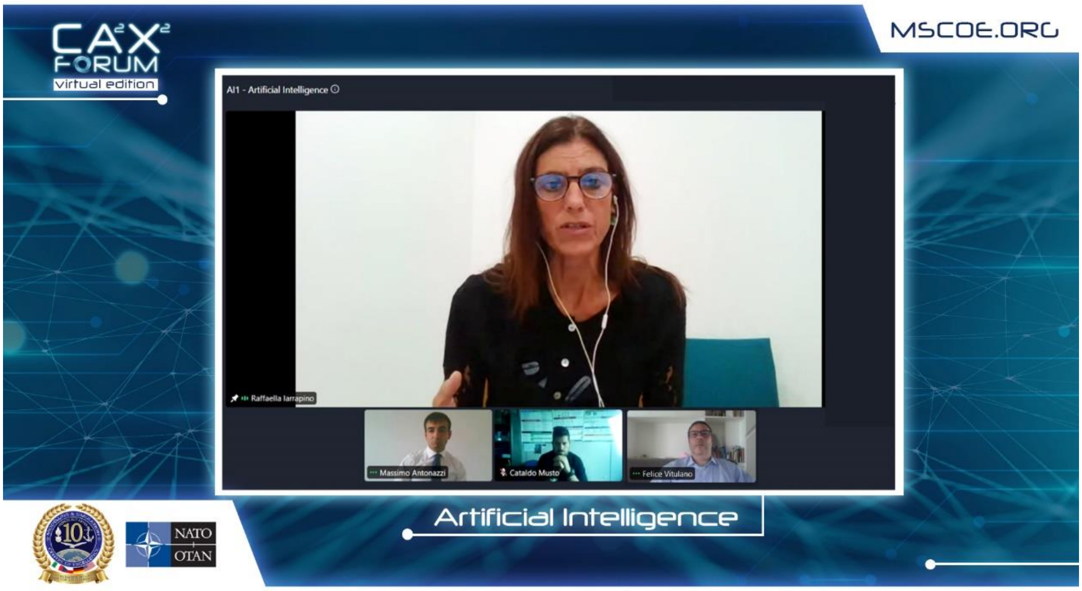
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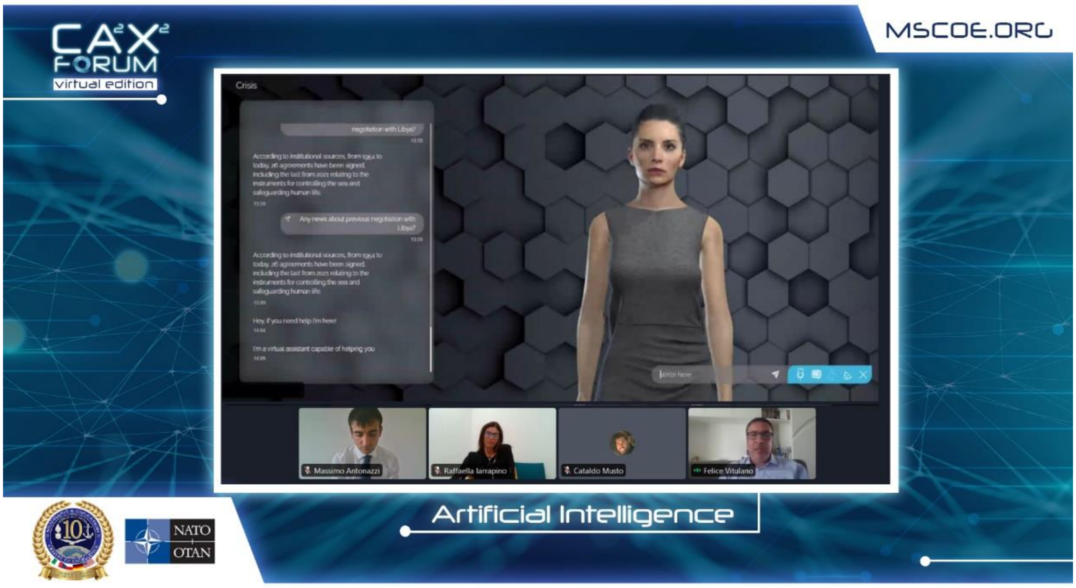
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