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Sustainability, Environmental Impacts and Resilience of Strategic Infrastructures

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Abstract

Constantly evolving hybrid threats and consequent changes in defense lead to develop new Methods and Solutions for Strategic Decision Makers. Indeed, recent conflicts demonstrate how Parties, which address properly such changes, take advantages over the ones who did not. In this paper, the Authors propose an innovative Wargame using M&S (Modeling & Simulation) that address issues related to protection of Strategic Assets and Critical Plants at Sea, including FPSO (Floating Production Storage and Offloading Unit), Off-Shore Platforms, Seabed Fields, Pipelines, Underwater Cables, Off-Shore Wind Farms, etc. It is evident the importance to protect these assets and their strategic value for a Nation as well as their impact on Energy and Networking Infrastructures. This subject has to deal with complex operations (e.g. multi domain, underwater environment) as well as to the development of new Strategies. In order to succeed it is evident the importance to prepare and develop new Capabilities within decision makers, with particular attention to Strategic Impacts on Country and Population, Operations over Multi Domains and related C2(Command and Control), Autonomous Systems Intensive Environments. Indeed, it is proposed an innovative Wargame that combines MS2G (Modeling, interoperable Simulation and Serious Games) paradigm with a framework using virtual 3D Chessboard as Command & Control tool, with the aim to improve awareness of decision makers regarding new generation of threats employed in hybrid multidomain conflicts and the related Risks and Impacts.

Keywords: Modeling and Simulation, Serious Games, Strategic Engineering, Wargaming, Strategic Off-shore Assets, Underwater Assets, Pipelines, Cable Data, Wind Farms, Energy, 3D Chess

1. Introduction

Rapid evolution of threats in terms of technology and methodology requires respective response in terms of protection from them. Indeed, nowadays it is always more common to speak about hybrid cyber-physical threats operating at different levels, variety of autonomous systems acting in distinct domains (both defense and attack roles) and other emerging threats, which all lead to creation of new concepts to address the evolving problem of the defense, such as Joint All-Domain Command and Control (JADC2) (Lingel et al., 2020). Obviously, in order to be able to deal properly with such threats, new approaches to development of decision makers are required (Mazal et al., 2019a). The Decision Makers as well as their staff and procedures need new solutions to address these problems respect challenging environments such as Marine Offshore and Underwater (UW) contexts. In this sense, this paper proposes an innovative approach to develop new generation Wargame systems using AI & M&S.

2. Complexity

This case introduces several complexities related to internal aspects such as perception within underwater environment where acoustics, thermal layers, sea bed clutter produce quite challenging environments; at the same time there are complexities related to hundreds of entities and platforms moving around and interacting where some threats could hide as well as all the cyber spaces and its own specific activities. Moving up at Strategic Level, the Impacts of failures on Energy or Data Networks introduce other kinds of multi correlated sets of elements interacting dynamically over different time horizons and affect Population, Institutions and the whole Country.

Indeed, in this research, the authors propose multi-domain Wargame integrated with Intelligent Agents (IA) including innovative control mechanisms, devoted to improvement of preparation of the Decision Makers.

Sometime, a phrase “3D Chess” is used to describe planning or strategy, even with ironic meaning, considering that these games result overly complex. However, in this research the authors took this concept as inspiration for creation of a new component of an innovative Wargame including different components for addressing protection of critical Marine Infrastructures and proper decision making:

- Interoperable Stochastic Simulation
- Immersive Multiplatform Serious Game
- Intelligent Agents driving Entities
- Strategic Command and Control Framework

The overall system is CAPIAS (CAbles, Pipelines, marine Infrastructures & Autonomous system: protection & Simulation), a Simulation Engine developed by SIM4Future, member of Simulation Team and Spinoff of Genoa University; CAPIAS has been integrated with the above-mentioned elements in order to create CAPIAS Wargames that include also a virtual 3D Chessboard, which represents one of the key interactions for the Players to address Strategic Issues.

The proposed interaction mechanism differs noticeably from strategic computer games, familiar to many people. Indeed, gaming industry tends to show to the user unrealistic expectations about interaction with units and assets, often allowing to the player to give direct individual fine-grain commands and showing precise and clear view of the situation, at maximum hiding part of it by fog of war. Contrary to this, the decision makers are normally expected to act as leader of complex organizations through their staff along hierarchical command chain down to low level controlled individual units that are still able to take point decisions and apply some kind of degree of freedom in execution of orders respect on very limited knowledge and reliable information (Autellet et al., 2022).

These contexts are very well covered by VUCA definition that need to deal with Volatility, Uncertainty, Complexity & Ambiguity.

Vice versa, exercises for decision makers in similar scenarios are often tabletop ones, which do not allow concise representation of target scenario and are rather based on gut feeling of players without too much attention to real details and technological/operational issues that are critical for success or failure. Moreover, a strategic game based on flat paper or digital map does not provide proper perception of multi-domain nature of modern conflicts. Modern conflicts have evolved, frequently involving the coordinated operation of assets across diverse domains including underwater, water surface, ground, air, space, and notably, cyber space. Additionally, there's an increasing emphasis on additional layer, the cognitive warfare, which seeks to influence and disrupt the decision-making processes and perceptions of adversaries, adding another dimension to the complexities of contemporary critical scenarios (Claverie, 2022). Hence, using traditional approaches for training of decision makers, it could be difficult to properly explain the existing situation, while planning of complex multi-domain actions and counter-actions could be even harder.

To address these issues, the authors propose a solution, capable to take benefits of simulation-based wargames that combine different levels by adopting the Paradigm (Modeling, interoperable Simulation and Serious Games) over a stochastic Agent Driven Simulation (Bruzzone et al., 2018c). At the same time, the authors propose innovative high-level approach to control assets through the 3D Chessboard that assign high level task to IA to be distributed over the individual platform, autonomous systems, swarms, team on the realistic playfield simulation (Bruzzone, 2023). Indeed, Serious Games and Simulation shown to be an effective tool for training and education even for Commanders and High Decision Makers (Bruzzone et al., 2022a).

3. State of the Art

Simulation is considered to be one of pillars of modern training; for instance, Computer-Assisted Exercises (CAX), characterized by generation, movement and management of forces in synthetic environment, are very important part of training process (Bruzzone & Massei, 2017; Cayirci & Marincic, 2009).

A more specific example in which simulation is used to support training of decision makers is SIMCJOH (Bruzzone et al., 2015). Among others, this solution addresses problem of interaction between peacekeepers and civilians, allowing to the decision maker to choose course of action in order to solve tension. Indeed, in this case, utilization of intelligent agents allowed to reproduce human behavior in terms of stress, fatigue etc., hence, to propose a realistically evolving scenario as well as proper reactions to actions of the player (Massei et al., 2014).

Apart from training, the simulation could be used to evaluate possible outcomes of different scenarios, to perform “What if?” analysis (Banks, 1999).

Figure 1. CAPIAS Simulator view

One example of such solution is T-REX, which evaluates risks of hybrid cyber-physical threats on a city and industrial facilities (Bruzzone & Di Bella, 2018). Among others, T-REX proposes scenario in which a facility is attacked by unmanned vehicles, preceded by cyber-attack which disables its defenses. Interestingly, similar attack was used a couple of years after development of the solution in attack on Aramco refinery. Another important topic is related to protection of critical infrastructures, caused either by accident or by purpose, and to relative crisis management (Rinaldi, 2004). In particular, ALACRES2 project addresses emergency management in seaports and such scenarios as leakage of dangerous substances, release of toxic gases as well as explosions (Bruzzone et al., 2022b). Indeed, the simulator deals with the problem of training of decision makers in crisis management and allows to evaluate efficiency of taken actions, in terms of time, damage and number and characteristics of employed assets. Similarly, it could be used to support creation of emergency procedures by testing various hypothesis.

Indeed, simulation is often used to support planning of operations and relative training (Honig, 2004; Negahban, A., & Smith, J. S, 2014; Gaudreault et al 2010). For instance, MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive Simulation) addresses problems related to the ship traffic in the context of piracy and other illegal operations. Indeed, it allows to the decision maker to develop an inspection plan for vessels, which maximizes efficiency of employed assets (Bruzzone et al., 2016). Similarly, simulation could be used for evaluation of different scenarios of crisis management after natural disasters. For example, a model based on Intelligent Agent (IA) Computer Generated Forces (CGF) was employed to support planning of country reconstruction after Haiti earthquake in 2010 (Bruzzone, 2013).

Apart from specific scenarios, in the past, various authors addressed more conceptual problems, such as necessity of development of efficient command and control systems. For example, it is highlighted importance of new approaches to big data visualization in joined operation command and control systems (Liu & Su, 2018), necessity of innovative approaches in preparation of decision makers (Bruzzone et al., 2019), integration of computer support in the decision-making process (Stodola & Mazal, 2017) as well as employment of Artificial Intelligence (AI) (Schubert et al., 2018). Obviously, as the framework of interest keeps evolving at high pace, in order to be competitive, it is necessary to constantly create, test and introduce innovative solutions to address new threats. Indeed, solution of highlighted problems should be addressed on different levels, including preparation of new generation of strategic engineers (Bruzzone et al., 2018b).

4. Proposed Solution

The proposed scenario is related to protection of critical offshore infrastructure. In particular, it is developing in a chosen part of a sea, where are present two oil rigs with their underwater wells, off-shore wind farms with corresponding power cables as well as internet cable. Indeed, such environment is specifically configured to be a potential target for threats of different nature, such as Unmanned Airborne Vehicles (UAV), which are aiming wind farms and surface parts of the rigs, trawlers with divers targeting for low-depth parts of infrastructures, Autonomous Underwater Vehicles (AUV) seeking for deep-water parts of rigs etc. Furthermore, parts of the infrastructure could be subjected to cyber-attack, disrupting production, data exchange etc. Hence, the player representing attacker side aims to damage the critical infrastructures and to compromise activity of the target systems. In this case, the focus on utilization of autonomous vehicles is imposed by observed trends (Mazal et al., 2019b). Vice versa, another side acts to reduce such damage as much as possible. In particular, the defending side could employ surface patrol boats, fixed and rotating wing UAVs, AUVs. Finally, both players are allowed to perform actions in cyber space, by compromising or protecting involved assets. The main component of the proposed solution is the CAPIAS simulator (Bruzzone, 2023). CAPIAS is a Solution using M&S, AI and XR for Protection of Critical Infrastructures such as UW Fields, UW Cables and Pipelines, Off-Shore Platforms, Wind Farms) respect Different Assets (e.g. Autonomous, Cyber and Conventional Assets) both as Threats and Defenders operating over Multiple Domains. CAPIAS adopts Strategic Engineering: the new discipline supporting Decision Makers by combining the use of M&S, AI, Data Analytics in closed loop with Big Data from the field over Complex Systems Strategic Engineering Solutions, such as CAPIAS, allow to Develop & Test: Ideas, Concepts, Tactics & Strategies, new Systems and even Decision Mindsets. Indeed, CAPIAS has been used in synergy with STRATEGOS, the new International Initiative in this sector by Simulation Team, Genoa University in synergy with SIM4Future and many others Entities. Recently the authors proposed an innovative instrument for evaluation of hybrid threats in the context of offshore infrastructure protection.

In particular, CAPIAS presents scenarios involving oil rigs with their extraction wells, offshore wind farms, underwater pipes and cables. At the same time, involved sides are represented by assets of different nature and belonging to distinct domains. For example, the defending side needs to identify malevolent ships among trawlers and prevent them from damaging infrastructure. Vice versa, the attacker works to maximize such damage. The scenario involves operation in six domains, namely: seabed, deep water, water surface, air, space and cyber space.

Another essential component of the overall software solution is the 3D chessboard, which is an innovative mechanism to control units in multi-domain scenario. Indeed, it is created to provide information about the scenario in intuitive way, at the same time, to facilitate control of the units, especially that ones capable to move across multiple domains. The 3D Chessboard configuration in this scenario is adapted to represent the target scenario with sufficient level of details. In particular, it is required to separate efficiently and intuitively the levels (e.g. water surface, air) and to make cells of single level of right size. Indeed, in order to keep this serious game clear and intuitive it is required to avoid too small cells, as in this case the environment could become confusing, while some big assets, such as ships and oil rigs, could have size bigger than single cell, making the 3D environment less intuitive than it should. Vice versa, cells of big size would imply presence in the same cell of multiple assets of different nature, e.g. wind farm and oil extraction rig could fall in the same cell, creating confusion. Considering this, for the target scenario the authors choose to employ square cells with side of 750m. At the same time, heights of levels vary, as sea floor and surface are rather shallow (25m), while the height of underwater and air layers is in order of hundreds of meters. Following figure demonstrates view of the Chessboard of a decision maker, commanding both sides of the conflict.

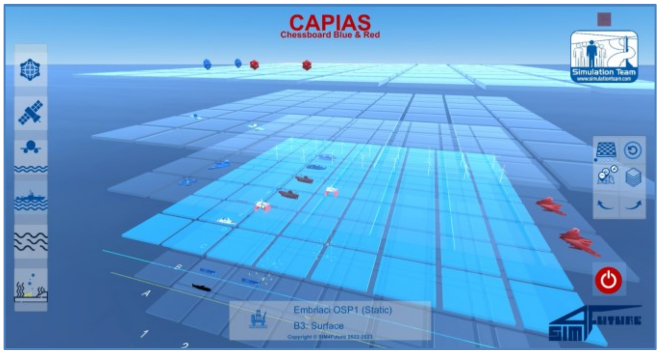

Figure 2. 3D Chessboard view

Obviously, utilization of an innovative 3D chessboard could be challenging for new users. To address this issue and to improve overall user experience, it was implemented a series of controls aimed to assist to the decision maker in situational awareness and in commands. In particular, after usability verification conducted with test audience, it was decided to add a series of point-of-view controls, such as capability to switch quickly from 3D to more familiar top view, function to highlight reference points on the chessboard (e.g. oil rigs) as well as ability to see only selected layer, neighboring ones or all levels at once. All these functions demonstrated to be of a great assistance to the user, by allowing rapid change of view and of quantity of presented data.

Combination of described controls allows to the user to quickly and effectively give orders to controlled assets, by dragging and dropping icons associated with commanded assets. Indeed, each piece could represent different kind of commanded structure, either it is a single ship or a swarm of unmanned vehicles. This control mechanism also allows the user to transfer some of assets among reachable domains; for instance, underwater vehicles could operate on seabed level, in deep water as well as to arrive up to sea surface, at the same time, cyber-space assets could be placed on any level. Indeed, cyber-space assets are allowed to act on an assets in single cell (e.g. to block communication or to protect it from such attack) or on bigger area, trying to disrupt or protect bigger number of assets, but with reduced efficiency. Example of pieces movement is shown in the next figure.

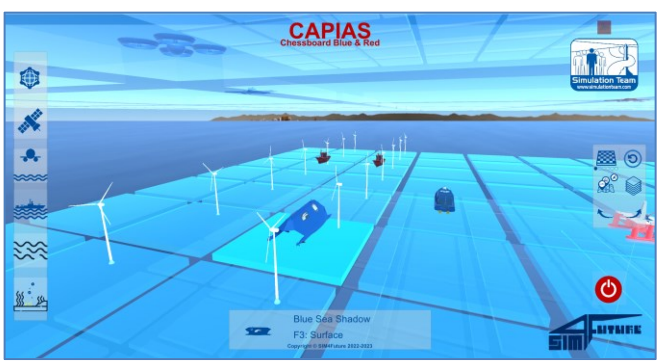

Figure 3. 3D Chessboard movement of a piece

Once the user moves a piece to a new position, the CAPIAS simulator receives respective order and commands assets. For example, it simulates their transfer to new position, including collision avoidance and proper interactions among them, analyzes surrounding environment and decides which action to perform. For instance, in case if a patrol boat is commanded to reach an area in order to protect it, once reached, it will start to check assets in its proximity in order to identify and block possible threats. Vice versa, assets of attacker side will try to find a suitable target in designated area in order to produce maximum damage, while shunning from assets trying to protect it. Apart from the CAPIAS Simulator and 3D Chessboard, another important part for scenario execution are Observers. These software are based on the same environment as the CAPIAS Simulator, while used to visualize the state of scenario as it is calculated by the simulator. An important detail is that this approach allows any employed device to run as simulator or as observer, whether it is a computer, smartphone or even Mixed Reality headset. Essential component which makes devices and application work together is the Gateway, which is an application, created to facilitate data exchange between various systems. Indeed, in order to make proposed solution compliant with HLA (High Level Architecture) interoperability standard, it is necessary to address such problems as poor support of programming languages by common RTI (Run-Time Infrastructure) implementations; moreover, as RTIs are not interoperable among different vendors, it is useful to create an additional middleware, in order to make target applications independent from exact implementation and version of used RTI. To address these issues, the authors used updated version of previously developed HLA Gateway, which is capable to interoperate with RTI implementations of different vendors, while performing data exchange with the simulators using WebSocket (Bruzzone et al., 2021). Using this architecture, it is possible to guarantee fast data exchange among different used systems, while the overall simulation state is aligned with external simulators connected by HLA. Following figure illustrates the general architecture of the solution.

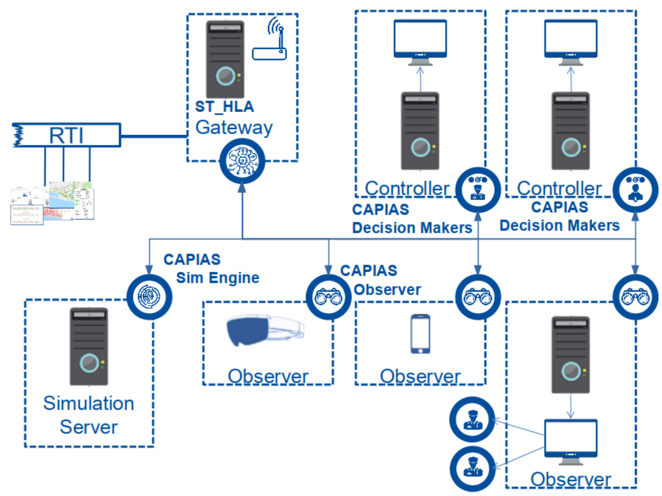

Figure 4. System architecture

This architecture demonstrated sufficient scalability and resilience, while being capable to run even on low-performance consumer level hardware.

5. Results

In order to perform evaluation of efficiency and usability of proposed solution, the authors conducted tests involving Subject Matter Experts (SME), done during specific field-related events. Considering that the proposed system is extremely flexible in its configuration, the authors chosen to employ quite complete solution, composed of CAPIAS simulator, ST HLA Gateway, 2 3D

Chessboards (attacker and defender) and multiple Observers: 2 Desktop (for convenience of each chessboard player), 1 Android and 1 Hololens 2nd generation. This configuration allowed to each player and to supervisor to have complete control on the situation. Based on this configuration, it was conducted a series of tests, aimed to identify qualitatively the user experience from point of view of experts as well as to detect possible errors in implementation. The tests shown high level of engagement of the players, while the main limitation is related to time required for familiarization with innovative controls of the3D Chessboard and with rules of the serious game.

6. Conclusions

Nowadays, presence of hybrid threats and utilization of constantly evolving technological solutions in the conflicts, leads to necessity to adapt accordingly also training of decision makers, who are expected to deal with them. Indeed, approaches to security and infrastructure protection which were effective tens of years ago shown to be poorly suitable to address modern threats, while a side which fails to support evolution of its defense paradigms will most certainly suffer significant losses in a conflict with a one that stays up-to-date.

To address this issue, the authors propose an innovative serious game for decision makers, which addresses hybrid threats in the context of protection of the offshore critical infrastructure. Moreover, to deal with multi-domain nature of modern threats, the authors propose an innovative approach to improve situational awareness and capability to give orders, resulted in a creation of a virtual 3D Chessboard.

Testing conducted with involvement of the experts in the field and decision makers shown big interest in the proposed approach as well as demonstrated efficiency of the proposed interaction mechanisms.

References

Autellet E., Masiello C. (2022) “Wargaming Initiative for NATO”, WIN 2022, Paris, October 18-19

Banks, J. (1999, December). Introduction to simulation. In Proceedings of the 31st conference on Winter simulation: Simulation---a bridge to the future-Volume 1 (pp. 7-13).

Bruzzone A.G. (2023) “CAPIAS Wargame Demonstration”, Tutorial at WIN 2023, Rome, June 26-28

Bruzzone A.G., Sciomachen A., Cepolina E., Giovannetti A., De Paoli A., Ferrari R., Gotelli M., Pedemonte M., Gadupuri B., Fabbrini G. Martella A., Monaci, F. & Bucchianica,L. (2022a). Serious games, simulation and IoT/IIoT for improving harbor performance. In proceedings of the 24th International Conference on Harbor, Maritime and Multimodal Logistic Modeling & Simulation (HMS 2022).

Bruzzone A.G., Massei M., De Paoli A., Ferrari R., Gadupuri B., Reverberi A., Cardelli M., Fancello G. & Frosolini M. (2022b). Innovative Virtual Lab for Improving Safety and Port Operations. Proceedings of the 24th International Conference on Harbor, Maritime and Multimodal Logistic Modeling & Simulation (HMS 2022).

Bruzzone A., Sinelshchikov K., Pernas-Álvarez J., Giovannetti A., Ferrari R. & Gadupuri B. (2021). Interoperable Simulation for Space Logistics & Operations for a Moon Base. In Proceedings of the 20th International Conference on Modeling & Applied Simulation (MAS 2021), pp. 190-193.

Bruzzone, A. G., Massei, M., Fabbrini, G., Gotelli, M., Di Bella, P. & Pusillo, L. (2019). Libra ad bellum novum: a political and military escalation in the near east as scenario for support advanced strategic decision making. In Proceedings of the 2019 Summer Simulation Conference (pp. 1-9).

Bruzzone, A. G. & Di Bella, P. (2018a). Tempus Fugit: Time as the main parameter for the Strategic Engineering of MOOTW. Proceedings of WAMS.

Bruzzone, A. G., Massei, M., Cianci, R., de Gloria, A. & Sciomachen, A. (2018b). New Educational Programs Based on M&S for Strategic Engineering. In proceedings of Workshop on Applied Modelling & Simulation (p. 42).

Bruzzone, A. G., Massei, M., & Di Matteo, R. (2018c). Modeling, interoperable Simulation and Serious Games (MS2G) for healthcare and first responders in disasters within industrial plants. In Proceedings of the 50th Computer Simulation Conference (pp. 1-11), July.

Bruzzone, A. G. & Massei, M. (2017). Simulation-based military training. Guide to Simulation-Based Disciplines: Advancing Our Computational Future, 315-361.

Bruzzone, A. G., Massei, M., Di Matteo, R. & Maglione, G. L. (2016). Model of Advanced Planner for Interoperable Computer Interactive Simulation. In proceedings of I3M, Larnaca, Cyprus, September, 26-28.

Bruzzone, A. G., Massei, M., Longo, F., Nicoletti, L., Di Matteo, R., Maglione, G. & Agresta, M. (2015). Intelligent agents & interoperable simulation for strategic decision making on multicoalition joint operations. In proceedings of DHSS2015, Bergeggi, Italy.

Bruzzone, A. G. (2013). Intelligent agent-based simulation for supporting operational planning in country reconstruction. International Journal of Simulation and Process Modelling, 8(2-3), 145-159.

Claverie, B., & Du Cluzel, F. (2022). “Cognitive Warfare”: The Advent of the Concept of “Cognitics” in the Field of Warfare.

Cayirci, E. & Marincic, D. (2009). Computer assisted exercises and training: a reference guide. John Wiley & Sons.

Gaudreault, J., Forget, P., Frayret, J. M., Rousseau, A., Lemieux, S., & D’Amours, S. (2010). Distributed operations planning in the lumber supply chain: Models and coordination. International Journal of Industrial Engineering: Theory, Applications and Practice, 17(3), 168-189.

Honig, B. (2004). Entrepreneurship education: Toward a model of contingency-based business planning. Academy of management learning & education, 3(3), 258-273.

Lingel, S., Hagen, J., Hastings, E., Lee, M., Sargent, M., Walsh, M., Zhang, L. & Blancett, D. (2020). Joint all-domain command and control for modern warfare. Santa Monica, RAND Corporation.

Liu, G. & Su, Y. (2018). Study on big data visualization of joint operation command and control system. In Big Data–BigData 2018: 7th International Congress, Held as Part of the Services Conference Federation, SCF 2018, Seattle, WA, USA, June 25–

30, 2018, Proceedings (pp. 372-380). Springer International Publishing.

Massei, M., Poggi, S., Agresta, M. & Ferrando, A. (2014). Development planning based on interoperable agent driven simulation. Journal of Computational Science, 5(3), 395-407.

Mazal, J., & Bruzzone, A. G. (2019a). NATO needs of Future Strategic Engineers. In Workshop on Applied Modelling & Simulation (Vol. 35).

Mazal, J., Bruzzone, A., Turi, M., Biagini, M., Corona, F. & Jones, J. (2019b). NATO use of modelling and simulation to evolve autonomous systems. Complexity Challenges in Cyber Physical Systems: Using Modeling and Simulation (M&S) to Support Intelligence, Adaptation and Autonomy, 353.

Negahban, A., & Smith, J. S. (2014). Simulation for manufacturing system design and operation: Literature review and analysis. Journal of manufacturing systems, 33(2), 241-261.

Rinaldi, S. M. (2004, January). Modeling and simulating critical infrastructures and their interdependencies. In 37th Annual Hawaii International Conference on System Sciences, 2004. Proceedings of the (pp. 8-pp). IEEE.

Schubert, J., Brynielsson, J., Nilsson, M. & Svenmarck, P. (2018). Artificial intelligence for decision support in command and control systems. In Proceedings of the 23rd International Command and Control Research & Technology Symposium "Multi-Domain C2" (pp. 18-33).

Stodola, P. & Mazal, J. (2017). Architecture of the advanced command and control system. In 2017 International Conference on Military Technologies (ICMT) (pp. 340-343). IEEE.