Towards Training and Decision Support for Complex Multi-Domain Operations

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ABSTRACT

In regard of rapidly changing political situations and new security risks, as well as of military challenges and scenarios NATO and allied forces are facing, new scientific findings and advanced technological developments have to be explored regarding flexible and effective education and training opportunities. In addition, military leadership and decision makers at various levels need timeliness decision support for increasingly complex situations and challenges. While last year´s Symposium was focusing on personalized training and training opportunities, this year the Symposium theme addressed especially complex multi-domain operations and training. This Symposium´s theme, its topics, and presented contributions selected by NMSG and the Symposium organizers address important advanced approaches, techniques and experiences for advanced education, training and decision support opportunities for complex multi-domain operations.

While a variety of M&S-methods, techniques and platforms are already widely applied over past years and decades, new concepts, advanced modelling and simulation methods and techniques, as well as new technological capabilities for effective use in M&S applications have to be considered for computer-based training and decision support. Examples for such developments offering new capabilities and opportunities for a wide range of M&S applications are for example methods of Artificial Intelligence, cloud computing and Software as a Service (SaaS). On the technological side, besides recent innovations of sensor and visualization technologies like Virtual, Augmented and Extended realities (VR/AR/XR), or of computer games, the permanent increasing capabilities of networks and high performance parallel and distributed computing infrastructures also provide additional opportunities for effective M&S training and decision support. This Symposium´s keynote, paper and poster presentations address these developments and report on new conceptual approaches, infrastructures, use case applications and on experiences from various nations. Overall, the Symposium offered the attendees an excellent overview about state-of-the-art, as well as on new perspectives and requirements for the near future.

Besides the indisputable M&S achievements and progress presented during this Symposium, I strongly recommend NMSG research and activities should be intensified on major arising problems like on measures to master the increasing complexity of System-of-Systems in reality and corresponding simulation applications. In addition, research and projects strengthening the development of a solid methodological groundwork along with tools substantiating trustworthiness, quality, correctness and validity (V&V) of M&S data sources, -tools and -results for their intended purpose.

Besides its scientific and technical substance, this covid-19-restricted hybrid Symposium was again perfectly organized and administrated by Dutch local organizers, as well as by NMSG. After last year´s NMSG-177-Symposium which was held as pure virtual event with a similar main theme and which had addressed basically the same M&S community, the attendees really enjoyed the discussions and face-to-face networking opportunities offered again this year besides interesting presentations. The organization of this hybrid event can serve as a model for organization of future symposia, workshops or technical meetings, as it can facilitate and motivate enlarged attendance.

Keywords**:** *Modelling and Simulation (M&S) based training and decision support; Formal modelling methods; M&S tools and platforms; M&S support for multi-domain applications; Artificial Intelligence (AI) applications; Sensor-based data acquisition for M&S; Virtual, Augmented, Mixed Reality (VR/AR/MR) applications; Challenges for future scientific research and technical applications of M&S*

1.0 INTRODUCTION

For several reasons, NATO is facing rapidly changing threats and new political, military and technological challenges. On one side, regarding recent geopolitical, military and economic developments, military forces have to be aware of and consider these trends in their future planning and development processes. Also considered have to be situations for example caused by social conflicts or natural disasters like earthquakes, catastrophic weather situations, or a pandemic with all the consequences we recognize right now with covid-19.

NATO as an alliance has to be prepared for a wide range of increasingly complex multi-domain operations of multi-national and joint operations of air, land, maritime, cyber and space forces. This requires that NATO force elements at all levels, from Command Headquarters to Tactical Elements, should be enabled to react on changing or even new military scenarios and suddenly emerging threats. Taking also into account the pressure to develop and apply time-, resource-saving and cost-effective methods and technological tools and infrastructures, this requires improved collaboration and knowledge transfer among nations, especially regarding new developments and exchange of expertise.

On the other side, besides already applied and available experiences with modelling and simulation (M&S) tools for education, training and decision support, rapid technological advancements as well as innovations of digitalization offer new opportunities. In this regard, for example sensor technologies, cloud-services like SaaS, methods of artificial intelligence (AI), data analytics, serious game technologies, or virtual, augmented, mixed reality tools (VR, AR, XR) offer new opportunities but also new challenges for advanced M&S application. Regarding rapidly evolving technological advancements, the exchange of expertise and transfer of knowledge e.g. regarding usability, effectiveness, user-acceptance and cost-efficency is of increasing importance for the alliance. Besides these challenges, it is obvious, that the use of these technologies contributes to the increasing amounts of data (“big data”), to increasingly complex tool and software applications, and to M&S-“System-of-Systems” implementations. Therefore, an increasingly major challenges concern mastering of M&S- systems complexity, their correctness, validity and quality.

2.0 THEME OF THE SYMPOSIUM

As summarized in the introductory remarks, NATO and allied nations are involved in a wide range of current operations, changing scenarios, and have to be prepared for potential new military conflicts and threats. In this regard, these challenges require additional efforts and actions to provide cost-efficient, effective and resource-saving training and decision support tools and infrastructures, on one side, and in view of recent technological improvements and innovations, on the other side. In this context this year´s Symposium theme addresses especially complex multi-domain operations at various levels. Therefore, also considering improved technological opportunities e.g. for sensor-based data collection and storage, for advanced methods of “data analytics” or of artificial intelligence offer along with advanced visualization techniques like VR/AR/MR, with parallel, distributed or cloud-computing new opportunities for simulation-based training and decision supporting environments. In this regard, the organizers of this Symposium have selected the theme “Towards Training and Decision Support for Complex Multi-Domain Operations” asking in the Call for Papers for corresponding paper submissions of NATO member states (see Symposium´s Programme structure in the Appendix). Finally, the Programme Committee has selected 20 presentations out of around 40 submissions accordingly.

3.0 PURPOSE AND SCOPE OF THE SYMPOSIUM

Main objective of this Symposium was to provide NATO nations an overview of state-of-the-art and trends of advanced M&S methods, technologies and applications for improving training and decision support opportunities, in general. This year, the Symposium focused especially on multi-domain operations with advanced M&S training and decision support opportunities, based on new concepts, innovative technologies, practical applications and gained experiences. In this regard, the theme and scope of the Symposium and its presentations were well selected aiming contributions at the following five topics:

- M&S in Support of Complex Multi-Domain Operations
- Training Innovations
- Decision Support Innovations and Applications
- Towards Capabilities
- Novel Approaches

From the Technical Evaluators point of view, these topics were very well selected for following reasons:

M&S in Support of Complex Multi-Domain Operations: Facing sometimes rapidly changing or even new geopolitical situations, military scenarios or threats, NATO forces have to be prepared for flexible and quick analyses, response and operational readiness. In this regard, advanced M&S methods and technologies are key instruments, especially if complexity of arising problems to be considered is manifold. Therefore, improved exchange of knowledge and expertise, interoperability of M&S resources for effective training and decision support at all levels and across the alliance is urgently required. Nations have to be prepared and trained for quick and close collaborative planning and analyses of optional solutions for multi-national and multi-domain operations. Accordingly, updated or new operational guidelines, technologies, tools and system components etc. for multi-domain operations as well as for adequate training capabilities have to be available for rapid application to known and unknown scenarios or threats.

Training Innovations: Regarding rapid technical advancements, e.g. game engines, visualization technologies like VR, AR, MR, or advanced and meanwhile cost-efficient sensors, but also applicability of advanced software methods and tools, e.g. Artificial Intelligence (AI) or Data Analytics (DA), applications for computer-based education and training systems have rapidly evolved and their applications are wide spread even in everyday life. Compared to traditional life training or classical computer-based training tools, these enhanced methodological and technological opportunities enable also new ways and implementations of advanced didactic concepts for effective, cost-efficient training. Examples include serious games, or personalized, time and location-independent and personalized training for individuals and limited groups of trainees. These didactic concepts and technological advancements offer together new capabilities and application opportunities for cost-effective military training opportunities at different levels of command.

Decision Support Innovations and Applications: On-demand decision support for commanders at all levels is of increasing importance and very challenging for several reasons. Nations and NATO commands want continuously to be on-alert to identify new or resurgence of old threats. They want to be able to make the right decision on the course of action (COA) taking into account changing scenarios, before escalation to a conflict or to aid decisions during operations. By use of real world data - increasingly available with spreading application of sensor technologies - together with available data analytics and M&S capabilities, projections for potential outcome of emerging threats are achievable, as well as tests and optimization the COAs needed to mitigate those threats. Depending on actual context and time constraints, real data collection and analyses, model development, simulation and testing of the actions will have to be often done in faster-than-real time to assess the threats and to pre-select the best feasible solutions. Therefore, on-line M&S-based operational decision support tools are required to support strategic and tactical command staff as part of the command and control system.

Directed Towards Capabilities: Dynamically changing political or military scenarios, new threats – like in cyber world or in space – as well as technological advancements require permanent adaptation and improvement of current decision support and training infrastructures. Advancement of decision supporting capabilities based on modelling and simulation and data science will be critical to ensure forces are prepared, ready, and have the right tools to overcome whatever threats they may encounter now or in the future. Development and use of advanced technologies will be essential to provide military forces rapidly with the required results gained by M&S tools, machine learning and data analytics applications. Delivering these results at the point of need whilst interacting with other national components and NATO organizations at on-demand pace will be essential to ensure NATO forces are ready to rapidly response and make the right decision for success, not only in terms of successful outcome after a conflict but also in terms of avoiding escalation to a conflict as part of NATO's Rapid Response Force.

Importance of considering Novel Approaches: Wide spread digitalization, emerging and future trends in scientific research and technology can provide improved or even new opportunities to meet the demands of on-demand (distributed) M&S capabilities for current and future training and decision support. Therefore, advanced education and qualification methods, technology trends, as well as current developments and expertise from the commercial and public world - particularly from the Gaming Industry and ICT sectors - have to be considered and exploited in the military context. How these developments, trends and experiences can be integrated together with those developed by defense industry should be always in the focus of NATO S&T activities. It will be essential to ensure that M&S tools and architectures are designed to be enduring and continuously improved to keep pace with new technology trends like virtual or augmented virtual action capabilities, or advanced methods of machine learning and data analytics.

This year, the 2-days hybrid Annual NMSG-Symposium held in the naval barracks in Amsterdam was opened by Dr. Wim Huiskamp, Scientific Advisor at NATO Modelling and Simulation Group (NMSG) and one of the organizers of this Symposium. In his short opening address, he welcomed around 80-90 attendees present in the audience while about 10-15 attendees were connected online virtually via video conference. Dr. Huiskamp mentioned the interest and positive feedback the Symposium organizers and the Programme Committee received on the Symposium´s Theme "Towards Training and Decision Support for Complex Multi-Domain Operations" and its call for papers: From about 40 paper submissions the International Programme Committee selected 20 papers for presentations and 5 poster presentations. Finally, the Symposium Programme included two keynote speeches, 16 paper and 5 poster presentations, as well as the Young Scientist Award 2021 presentation given by the award winner Paolo de Heer (NLD).

In his opening keynote, Mr. Auke Venema, Strategic Advisor for Netherlands (NLD) Ministry of Defense and member of NLDF-STB, summarized major strategic objectives and actions of NLD MoD and STO. Major objectives focus on strengthening partnerships, improvement of capabilities and new developments, as well as optimization of experience dissemination. He also reported on some current actions regarding an innovation defense initiative of government and industries, and on NLD´s plan offering a test center for robust logistics. He also mentioned increasing general interest in NATO for S&T. The keynote was followed by 16 paper and 5 short poster pitches and presentations. Symposium Programme and schedule are listed in the Appendix.

4.0 EVALUATION

For review of the Symposium´s scientific and technical contributions in view of the objectives mentioned above and regarding the oral presentations of papers, posters, as well as discussions and networking opportunities, different aspects have to be distinguished. On the one hand side, in accordance with the Symposium theme, advanced or even novel approaches of Modelling and Simulation (M&S) and Data Science (DS) concepts have to be considered. On the other side, regarding implementation and application efforts, advancements of hardware and software technologies have to be evaluated in view of demanded

capabilities and their practical applicability for military training and decision support. From a technological perspective, special focus was set on M&S, AI (Artificial Intelligence) and DS concepts, as well as on their applicability to improve training and decision support of complex scenarios and operations for various command levels. These aspects are subject of this review in subsections 4.1.1 and 4.1.2.

In addition, a summary of novel or advanced methodological and technological approaches which should be considered for strengthening NATO military forces, in general, is summarized in subsections 4.1.3 and 4.1.4. In section 4.2, this review is briefly summarized concluding with an overall evaluation of the Symposium´s contributions to the addressed thematic topics. In section 5, some suggestions for future consideration by NATO, especially by STO and MSG, are presented regarding future planning of multi-national M&S-Symposia topics, as well as for dedicated Workshops and for new NMSG-activities. Finally, general observations and conclusions regarding this Symposium are expressed, considering its value, major results and future challenges for NMSG, including its perfect organization.

4.1 Summary of Papers and Posters

At first, to structure this report thematically and for the ease of citation, the following presentations are grouped according the four thematic topics of the Symposium and numbered by their paper or poster number as given in the Symposium Programme (see attachment).

4.1.1 Papers and Posters on M&S in Support of Complex Multi-Domain Operations

The following list includes all contributions focusing on M&S support of complex multi-domain operations:

(1) Modelling & Simulation and Data Science to support commander's white picture

(2) Getting Battle Labs ready for Multi-Domain Operations: Main results and developments within the NLD MoD

(Poster 4) Autonomy Studio Tool: A Virtual Studio for Multi-Domain Complex Operations Simulation

In paper (1), the author Jan Hodicky emphasized the importance of including the wide range of impacts from the civil world with all its uncertainties, unknowns and assumptions in a "white picture" besides blue and red pictures in the Common Operating Picture (COP) to provide situational awareness to commanders at all levels. For the white picture, open source data resources have to be collected, analyzed and structured to support SACEUR´s Area of Responsibilities risk and resilience analyses like data of government processes, energy, food and water supply, mobility of people, as well as of communication and transportation resources. The paper also mentions that other, sometimes unexpected events like national disasters or interrupts of basic everyday supply of resources for the population require an overall picture which integrates these kinds of multi-domain information. NATO has to develop a resilience concept to manage or even absorb consequences of those shocking events.

Accordingly, NATO considers 7 baselines requirements as resilience measures to guarantee at least minimal availabilities of energy, food, water, communication, transportation, healthcare, as well continuity of governmental services. In this context this paper reports on an implementation of a Minimum Valuable Product (MVP) for resilience data analytics. This MVP implements some data science methods including big data analyses and machine learning techniques for real time analyses of real world data which enables to determine the actual situation with respect to the 7 baseline requirements. Besides this MVP, a second prototype implements an Aggregated Resilience Model which applies system dynamics and M&S-techniques to simulate, analyse and visualize civil preparedness by means of aggregated 7 baseline requirements. These two prototypes implement the proposed general architecture concept which combines

Resilience Data Analytics MVP and the Aggregated Resilience M&S prototype. These prototypical implementations and first applications enable 24-hour update analyses of the white and common picture, as well as predictive "what-if" analyses. Advancements of this concept focus on application of machine learning and natural language processing techniques in context of predictive analysis.

According its title "Getting Battle Labs ready for Multi-Domain Operations: Main results and developments within the NLD MoD", paper (2) reports on a Concept Development and Experimentation (CD&E) concept for multi-domain operations in synthetic environments. The concept is based on NLD MoD´s labs and capabilities of maritime, air, aerospace and joint forces battle field simulations, and for analyses to support and improve operational readiness. Main driving force for concept development is to enable multi-domain mission simulations linked to the already available battle labs and their simulation tools and some experimental analyses typical multi-domain operations. By means of operational analysis, a CD&E concept with 6 maturity levels and development activities including war game techniques, virtual environments, constructive and life simulations. The presentation summarizes an example of multi-layer integrated warfare analyses of military operations incorporating cognitive, virtual and physical dimension. Based on current experiences, the presentation also summarizes future demands for integrated warfare experimentation and analysis, for the availability of multi-domain battle labs, "white box" solutions as well as for federated CD&E.

In brief, these 2 papers deliver significant results, experiences and further challenges to enable up-to-date situational awareness of multi-domain scenarios as basis for predictive analyses of military operations. In paper (1), situational awareness for decision support of actions by military commanders require the analyses of the "white picture" besides the "blue" and "red" ones. The paper proposes and demonstrates how by application of data analytics and artificial intelligence methods for data analysis as input for an Aggregated Resilience Modelling approach can deliver the required decision support for multi-domain scenarios. Paper (2) addresses primarily establishment of battle labs for analyses of joint military operations in a synthetic environment representing multi-domain battle spaces. Experiences have been gained from CD&E experiments like information flow analysis or multi-layer analysis in regard of a tangible physical objects, as well as with regard to virtual persons and objects with their behaviour (cognitive aspects). Both contributions demonstrate the importance, feasibility and effectiveness of applying advanced M&S methods and techniques and of data science in context of complex multi-domain scenarios.

According to my view, for NATO and its military leadership such concepts and applications of advanced modelling and analysis techniques are of increasing importance to provide a complete picture of a real, multi-domain scenario as decision support for political activities and military operations.

4.1.2 Papers and Posters on Training Innovations

The following list includes contributions on simulation concepts and tools for innovative training:

(4) Innovative Automated Analysis Tools for After Action Review (AAR) using AI and M&S

(5) Live Air Training in a Synthetic Environment

(7) Deep Self-Optimizing Artificial Intelligence for Tactical Analysis, Training and Optimization

(poster 3) Learning Analytics in Military Training Simulations

According to its title, paper (4) proposes an "Innovative Automated Analysis Tools for After Action Review (AAR) ….". In most of today´s simulation-based trainings, AAR requires recording of events, state changes etc. for briefing, for replay, for visualization of actions and for root cause analyses. The paper summarizes results of a research project in which automated analysis tools for simulation-based AAR have been

developed. The implementations of these analysis tools offer the following capabilities:

(a) a graph modelling approach allowing automatic reconstruction of causality of event sequences;
(b) automatic generation operational diagrams of local forces, of tactical situations and their historical development, tactical lines or effects of missions;
(c) exploration of alternative options for actions can be analysed by interactive pictures.

For task planning, the paper proposes and explains application of linear logic instead of planning languages. Besides for AAR, the graph model approach enables also generation and simulation of alternative event sequences and actions.

MASA SWORD was applied to integrate these new approaches of automated AAR. Applying AI techniques, this M&S tool simulates "smart" behaviour of simulated units which behave as specified by doctrines in a simulated environment. MASA SWORD has been designed for operational analysis and for decision support. But now it can be also applied for training purposes like for command post training, logistic operation training or for warfare analysis, crisis and disaster management.

Paper (5) reports on developments for fighter live air training towards a distributed blended training environment. To reduce resources and costs for basic and advanced live air fighter trainings parts of the operational training can be downloaded on or emulated in a less expensive trainer aircraft. Another current training approach to save expensive flight hours is to offload some training content from live training to a synthetic simulation environment on the ground which requires high-bandwidth distributed network for real-time data transfer between distributed simulators and the aircraft to enable full mission training. MSGs 128 and 165 have proposed a common Reference Architecture for such joint and combined air operations. An advanced training concept presented in this paper is directed towards a blended air training concept. The paper summarizes major technical requirements for real time collaboration between downloaded and offloaded training elements on the ground and in the air, e.g. implementation of human-machine-interface by VR/AR head mounted display, distributed simulators for LVC simulation, LVC gateway and ground network requirements.

Without giving specific details, the paper also mentions that the blended training network enables comprehensive data collection of training missions as prerequisite for data analytics to improve training progress and effectiveness.

An innovative approach supporting tactical analysis, aircraft training and optimization problems by effective combination of commercial COTs computer games, advanced AI methods of reinforcement learning, Monte Carlo simulation and deep artificial neural networks is subject of paper (7). In the presented approach, simulation of a training scenario represents all relevant rules and physical constraints of the real scenario in a serious computer game while an external AI application controls the player(s) and avatars actions and behaviour who represent red and/or blue forces. Basically, intended goal and demands for an implementation of this concept are air defense, CD&E and procurement projects. For the current phase of the project a reduced test scenario for jet fighter training was implemented. An API allows enables direct interaction of the player(s) as well as external interaction by the with the Monte-Carlo-simulation of a Markovian planning and decision process externally also controlled by AI-based agents. The core of AI is - according to the authors - a "sophisticated" neural network-based Monte-Carlo Tree Search algorithm (MCTS) which combines iterative reinforcement learning with tree search techniques processed on problem-specific decision trees. Purpose of the MCTS – the expert – is to propose a list of "good" actions. The MCTS design includes a deep-neural network for construction of the problem-oriented decision tree. In an iterative process the MCTS algorithm searches from the proposed list of actions and the neural network mutually improve each other. To achieve fast learning, the agent is pre-trained before being used in the serious game. Results of the test case scenario demonstrate feasibility of the proposed concept and approach: An AI controlled red aircraft learned to fly a direct path from take-off to a target. Visible for blue radar, the route planning was

adapted to avoid recognition by the radar. Concept, its implementation and test case results offer a real innovative approach that should be also considered for a wide range of applications and scenarios.

In (poster 3), some use cases of a Learning Analytics (LA) application were presented in which data collected from trainee, instructor is subject of learning data analytics. Sequences of LA results are stored in a dashboard monitoring the trainee´s learning curve accessible to trainee and instructor as feedback. As use cases, some generalized results of training with a ship-handling simulator and a CV90 tank simulator were reported.

4.1.3 Papers and Posters on Decision Support Innovations and Applications

Technological advancements enable the design of increasingly complex models specifying big sets of input, state and output parameters. Consequently, those M&S-applications require significant amounts of reasonable data for simulation. Especially in case of decision supporting simulations quite often only uncertain, vague or even missing information is available but has to be represented in these models by assumption-based and stochastic simulation variables which results in exploration of huge state spaces for identification of preferable decision options. In these cases, data farming experimentation based on Design of Experiments (DoE) algorithms has to be applied for effective analysis of huge state spaces.

The following list includes contributions on M&S and AI in support of decision making processes:

(KN2) The Virtual Command Post – Experiencing today´s Technology in order to innovate tomorrows decision making

(6) 5th Generation Mission Planning: Integrated Systems and Algorithms

(8) Geospatial Analysis for Machine Learning in Tactical Decision Support

(12) Modelling and Simulation in NATO Federated Mission Networking (FMN)

(13) Simulation-Based Decision Support for the Logistic System of the German Armed Forces

(14) From the Game Map to the Battlefield – Using Deep Mind´s Advanced AlphaStar Techniques to Support Military Decision-Makers

(15) Decision Support within Complex Subterranean Operations

Presentation KN2 addresses basic problems of situation awareness and corresponding decision-making processes military commanders are facing in an increasingly complex and digitized world. Besides all beneficial advancements of today´s of technologies, digitalization also boosts availability of exponentially growing amounts of data, network capacities and of development and use of powerful but also complex System-of-Systems. Already today, but even more in the future these technological advancements will lead to further increasing complex scenarios in which commanders have to make their decisions despite volatility, uncertainty, ambiguity or incompleteness of information that will be available. In this regard, the concept of virtual command support is demonstrated by use of M&S-, digital twins, VR- and gaming technologies. Besides new opportunities enabled by technological advancements, commanders have to trust analyses of situational awareness and decision supporting tools and the delivered results. The presentation summarizes that building trust requires development of adequate concepts for rigorous application of data validation as well as interdisciplinary and multi-domain M&S. As key challenges, the presentation considers future research on concepts and advanced technologies towards digital awareness, use of digital twins and experiments with corresponding MVP applications.

Emanating from the same perspective, paper (6) considers on the one hand the diversity of threats, exponentially increasing amounts of data, higher systems complexity despite decreasing development times as one main challenge for successful mission planning. On the other hand, despite the permanently increasing amounts of data sources and data, analyses of context, validity and transformation of available data into useful information can be a time consuming process in regard of limited time available for mission planning. The paper presents results of the Dutch DoD funded project IMPACT which investigates supporting future mission planning of helicopter missions with Augmented Collaborative Technology. As main objective the IMPACT project considers the development of a mission planning tool that collects and integrates all kinds of data and information regarding e.g. mission, enemy, available forces, terrain, weather, or civil considerations relevant for planning CoA options. Algorithms facilitate the collection, selection and transformation into valuable information that is stored in a central database accessible for all those involved in the planning process. In addition, a screen-based application was developed that offers CoA visualization and collaboration among the planners via an Augmented Reality HMI. Besides supporting mission planning, mission commanders can access and see in virtual reality the same 3D visual at any location. Besides cyclic mission planning, the concepts allows cyclic application of this tool from optional CoA planning to rehearsal (Virtual Cockpit) and debriefing.

Supporting tactical mission planning for land operations has to include geospatial information of the terrain to be considered for selection of recommendable routes for COA´s in a given scenario. Paper (8) presents the vision that based on solid geospatial terrain information and on tactical terrain models, “optimal” tactical strategies and COA´s can be automatically generated. Defined by other projects, Tactical Spatial Objects are defined to link products for terrain analysis with products of tactical decision support. As for route selection various kinds of geospatial products are already available.

At first, the paper includes an overview of geospatial products classified in a tier-based hierarchical structure in which higher tier-level products are based on fundamental lower-level ones, like on sensor data and other sources. Furthermore, the sequence of process steps to be taken for finding “optimal” CoA elements are formalized as prerequisite for CoA automation applying machine learning techniques for creation of tactical terrain and mission models. The paper describes application of genetic algorithms for automated optimization of preferable routes and, furthermore, reinforcement learning techniques for selection of optimal tactical mission strategies. This basic approach demonstrates how favorable CoA´s could be determined for mission planning of land operations in a specific scenario. Feasibility of the proposed approach and utility of application of these ML techniques is demonstrated by two practical examples which demonstrate how mission planners can be supported for decision making. Finally, the authors future vision is that all steps of this sequential planning process of CoA can be automated to a high degree. This requires in addition to improve setup times for configuration of simulation models and runtime performance improvements of simulation experiments.

The following papers (12) – (14) report on interesting M&S decision support applications and experiences.

Paper (12) summarizes an ongoing major NATO-initiative called “Federated Mission Networking (FMN)” aimed to establish a common technical and training basis for NATO partners. For coalition operations, interoperability of all critical information systems, M&S standards, infrastructures and practices have to be available. General objective is “Day-Zero Interoperability”. The initiative follows a spiral approach to develop stepwise a solid foundation that shall enable allied forces for instant operational effectiveness before executing a mission. In particular, FMN offers a set of standards and practices for interoperability between allied forces in coalition operations.

This paper summarizes how FMN specifications are developed and shows how MSG-93 as “M&S Syndicate” contributes to this development. About 30 nations are cooperating for the development of currently 5 spirals and the roadmap. The presentation mentions points of view arising from sizeable cultural gaps between the operational focus of Allied Command Transformation (ACT), Allied Command

Operations (ACO) and the scientific and technology focus of NMSG S&T. The paper reports on current focus of MSG-193 on spiral 5 regarding the definition of information technology services and their interfaces concluding that internal interfaces among M&S systems should be documented in one document and interfaces to other FMN applications in another one. The paper also describes the role of FMN employing M&S for collective training of coalition partners CAX (Computer Assisted Exercises). It also summarizes M&S recommendations for FMN spiral 5 provided by the M&S syndicate concerning importance of FMN for mission rehearsal, C2-simulation interoperability (C2SIM), High Level Architecture (HLA) for M&S federations including the NATO Education and Training Network (NETN) FOM and M&S-as-a-Service (MSaaS). Conclusion is that NMSG has the opportunity in a successor activity of MSG-193 to further support the specification of FMN in spiral 6.

Paper (13) “Simulation-Based Decision Support for the Logistic System of the German Armed Forces”. Subject of this paper are applications of and experiences with simulation systems, as well as concept for autonomous systems in military supply chains. The authors report on 2 concrete projects for simulation - based decision support: Logistic simulation to test medical military rescue chains for robustness and sustainability. Scenario description in OSD (Operational Scenario Description) specifies structures and sequences of the scenario. The simulation system consisted of the 3 subsystems for patient generation and requests, others for transport and for treatment. The second use case was applied for an evaluation of utilization of a flying weapon system considering different status of these systems, like combat readiness, maintenance, training etc. Both use case applications demonstrated the analysis of supply chain bottlenecks, as well as how structural and procedural changes can improve overall logistics performance.

Paper (14) “From the Game Map to the Battlefield – Using Deep Mind´s Advanced AlphaStar Techniques to Support Military Decision-Makers”

Study results reported in this paper emanate from the assumption “…. that future warfare scenarios will be digital, with use of AI-assist command and control and of unmanned systems with a dramatic impact on the speed of combat operations.” Consequently, decision making processes will have to speed-up which requires even stronger support by and use of automation by advanced M&S- as well as AI-techniques. The paper reports on experiences gained from a study processed by German Army Concepts and Development Centre together with Airbus. Aim of the study performed with “ReLeGSim” was to evaluate feasibility and performance of an agent-based simulation in which agents are trained by reinforcement learning technique to act as battalion commanders. Feedback in form of rewards is returned to the individual agents to debrief and change their behavior. In ReLeGSim, combat events and attrition of all involved military units and fire support elements, of attackers as well as of defenders, are modelled and commands are given on the company-level. In the use case presented, opposing forces were modelled including reconnaissance units, tanks, helicopters or artillery or infantry fighting elements, all with different capabilities.

As the developers were geared to the AlphaStar algorithm for development of the “ReLeGSim” agent-based simulation reinforcement learning capabilities of the agents. Like for AlphaStar, only partial data and knowledge is available by the sensors of the players´ unit. Therefore, both conflicting sides have to update permanent their environment and situational awareness. The agents should learn policies, like specific patterns of behavior in given situations based on the agents´ observations. An agent strategy is represented by a policy network trained by a policy algorithm. The policy network offers feasible actions for the agent.

The paper describes the ReLeGs AI Architecture. Regarding the huge space of possible agent actions, there are 3 types of actions defined: no action, cancel action or request new action. In case of the latter type, the RL agent must select 58.000 actions at each discrete time step. For reduction of this selection process, an autoregressive action scheme was implemented, so that generation of a new action depends on previous actions taken. During training session, the agent tries to improve his reward depending on the selected reward function.

Finally, this excellent and ground braking paper presents some results of and experiences gained so far by this study. A major challenge for successful application of RL agents is computational speed and overall runtime performance. That requires to simplify and optimize the RL agents regarding computational speed which is still subject of this ongoing study.

Paper (15) “Decision Support within Complex Subterranean Operations”

This paper summarizes interesting results and experiences of a project performed by the research group NIKE of the Austrian Military Academy that aims at support for decision making, planning and training of complex underground scenarios like of operations in urban subways, in rail tunnels, in the canalization or even in nuclear waste deposits – scenarios that might neither be accessible nor visible. In such scenarios, data collection, integration and visualization of heterogeneous sources has to be available for support of decision making processes or for training. In such scenarios, especially in case of disturbing events, speed of information collection is more important than precision. In such cases, data has to be gathered as fast as possible from all kinds of data sources, like from 2D plans and maps, converted to 3D visualization, as well as from laser-scans, sensors and cameras if relevant for receiving a comprehensive operational picture. With RADIV (Rapid Data Integration and Visualization), a core process has been developed that satisfies these requirements. Besides applications for urban operations, it is assumed that such subterranean operations can be also subject and a challenge for military operations.

These project tools like BORIS (browser-based Orientation in Space), SOMT (Subsurface Operations Mission Tool) or FTMT (Fast Tunnel Modelling Tool) are being applied in this study for generating digital twins for quick visualization of such a scenario. Virtual replication of reality by digital twins enables virtual interactions within hidden objects and infrastructures. Visualization of such a scenario together with Extended Reality (XR) applications can accelerate decision making processes and support mission planning. This offers an immersive bird view to the mission scenario and the area of operation shared by cooperating users. The paper includes the underlying development process and tool set applied in this project and an impressive online mission planning operation was part of the authors presentation.

The authors conclude well that a process like proposed by RADIV will play an essential role for headquarters to improve rapid planning and decision making for subterranean operations.

4.1.4 Papers and Posters on Towards Capabilities

The following 2 contributions forward new capabilities for military forces decision support and training:

(16) Towards a NATO Reference Architecture for Joint Mission Training through Distributed Simulation

(17) Towards a Modelling & Simulation Capability for Training Autonomous Vehicles in Complex Maritime Operation

(18) How much is too much? Levels of AI Explainability within Decision Support Systems´ - User Interfaces for improved decision-making performance

As NATO is facing urgent needs to improve mission readiness and training of multi-national joint operations for rapidly changing scenarios, a MTDS (Mission Training through Distributed Simulation) reference architecture is proposed in paper (16). As budgets, resources and ranges for live trainings are limited, less live exercises are feasible. In addition, due to less preparation time for increasingly complex political and military situations, time frames for mission preparations within or between coalition partners have to be shortened.

Taking these trends and requirements into account, there are needs for a balance between live and simulated

training and exercises. That requires adaptations of MTDS capabilities among coalition partners for collective training – based on a common MTDS Reference Architecture (MTDS RA). In addition, adequate modelling and simulation tools and infrastructures are increasingly important prerequisites to meet current and future needs for effective training and mission readiness of a coalition. The proposed MTDS RA addresses perspectives for the different stakeholders: for nations, for NATO, for industries regarding required standards and products and implementations of synthetic environments, as well as for NMSG to provide a Reference Architecture for which standards, technologies, applications or guidelines can be defined. In past years, several NMSGs have provided valuable input towards a NATO MTDS vision, but still couldn´t establish NATO-wide capability for synthetic collaborative training. This paper describes an architecture framework for MTDS RA including an Enterprise Architecture, Reference Architecture and Project Architecture. It includes a description of architecture principles and persistent rules which determine the development of the MTDS Reference Architecture and MTDS Project Architectures. This includes also specification of architecture and solution building blocks, patterns as well as of architecture layers plus the MTDS technical framework. In the concluding remarks the paper notes the strong link between MTDS RA and the NATO C3 taxonomy. It also forwards the recommendation to NMSG to use RA as the reference for collective synthetic training, and notes the necessity to maintain the RA by successive NMSG task groups.

Paper (17) “Towards a Modelling & Simulation Capability for Training Autonomous Vehicles in Complex Maritime Operation” describes a maritime simulation framework (CMRE) which is interoperable with a robotics middleware (e.g. MOOS, ROS). This approach facilitates hardware in-the-loop simulation which allows to simulate external influences on autonomous maritime systems. Objective of this project of NATO STO CMRE is the development of a configurable maritime simulation framework (MSF) open for existing or new simulators to be required for simulation of new external effects to assist system designers in testing and in training of specific algorithms for autonomous maritime systems. The expandable simulation framework offers special purpose simulators cooperating as federates within a HLA-based distributed simulation federation of external effects. Specific simulators in this framework represent for example systems environment, sensors, cameras, communication and offer visualization especially for underground operations. Use cases presented in the paper are autonomous system algorithms for Mine Counter Measure (MCM) and for Anti-Submarine Warfare (ASW).

In order to train algorithms not just for benchmarking problems but also for learning from actual situations and problems of the real maritime world, quite often existing simulators have to be adapted or even new ones have to be developed. In this context, the developers have developed several simulators as reported in the paper. The paper describes in detail the MSF simulation framework, the RTI-middleware for HLA compliant simulators, some basic simulators, and the Viewer 3D Federate which shows the simulated scenario in a virtual environment. The authors also note, that MSF was developed as a framework to perform Verification and Validation (V&V), as well as Concept Development and Experimentation (CD&E) in case of new developments.

(Paper18) “How much is too much? Levels of AI Explainability within Decision Support Systems´ - User Interfaces for improved decision-making performance” addresses an issue of increasing importance: Can we trust the results of AI applications if the implemented AI methods are based on inductive models such as artificial neural networks applications? The authors of this paper note in their problem statement that nowadays AI technology is often implemented in decision support systems to ensure lower error rates and faster decision supporting processes in the view of complex scenarios like on a battlefield. With increasing complexity of the scenario and - as a consequence - the reasoning process of the decision support system, the need for explainable AI results is increasing. In addition, as the paper notes, for explanation the user should not be overloaded.

The paper reports on the authors research regarding “Explainable AI” (XAI) and refer to an AI-driven use case of military helicopters to find two appropriate landing zones in a terrorist scenario. Based on extensive research studies, the paper describes in its first part four XAI categories of explainability: model explanation,

prediction explanation, counterfactual checks and explanation by example. In addition, a set of four XAI user interfaces are defined with increasing level of transparency and control.

Second part of the paper demonstrates the experimental application of the decision supporting system with the proposed four XAI user interfaces and the performance results obtained with different users. The experiments show that for the simplest user interface provided users tend to make relatively quick decisions, probably as the user makes his or her own best guess. With the higher user interface levels providing more information to the user decision making time is increasing. From the experimental results the paper concludes that an average level – respective to the amount of information presented to the user for explanation – seems to favorable for most users. But nevertheless, the authors conclude that the explanation process should always start with the lowest level user interface presented to the user.

4.1.5 Papers and Posters on Novel Approaches

The "Novel Approach" session with its two papers, three posters and especially the NMSG-Young Scientist Awardee´s presentation provided an excellent insight into new conceptual and technical approaches on applicability and use case experiences of innovative technology applications for training and decision support, especially by application of various AI methods, VR/AR/XR tools, specific sensor simulation or gaming techniques:

(9) Opportunities for Military M&S to Capitalize on Gaming Technologies and Competences

(11) Virtual Cockpit – Making Natural Interaction Possible in a Low-Cost VR Simulator

(YSA) Multi Agent Reinforcement Learning Using Simulated Quantum Annealing

(Poster 2) Minds for Mobile Agents

(Poster 5) A Conceptual Model to Increase Political-Military Fusion Exercise Events through Synchronous Distributed Wargaming

(Poster 6) A Scalable Architecture for Rapid Terrain Analysis

In paper (9), the authors report on results of a study commissioned by the UK Dstl to support the research program "Mastering Architectures and Artificial Intelligence for Training and Education Efficiency (MAAITEE). The study results described in this paper are considered as a potential "… step change in MOD´s training and education for better prepared and more effective Armed Forces."

The study researched gaming technologies with respect to potential benefits for military training and education. In addition, the research was focused on identification of technologies and approaches for future Modelling and Simulation as a Service (MSaaS), reusability and scalability. In this regard, the study defined so-called heatmaps considering as its elements "gaming ecosystems" (x-axis of the heatmap) and "defense M&S requirements (on the y-axis). Each element of this heatmap (a tool or a company) is reviewed against each defense M&S requirement leading to a "heat score".

The paper includes a detailed description of the selected attributes of two heatmap elements. Besides the four upfront selected hotspots (game engines, cloud gaming, data and data analytics, and community), 54 additional hotspots result from these analyses. Relevance and expected benefits of these four hotspots for defense simulation applications, as well as their respective challenges and risks, are discussed in detail in the paper. As some other relevant hotspots were identified: Artificial intelligence, distribution of content and user generation of content, game development process and its documentation, education in gaming, e.g.

skills in programming, simulation games (like Microsoft Flight Simulator, or combat simulation series ARMA), or professional and electronic (e)-sports, e.g. including multiplayer games.

Major findings of this study show that a creation of "the gaming ecosystem" wasn´t possible, but a number of existing ecosystems are recognized as possible starting points. The "Konvoy Ventures" game ecosystem as evaluated as the up to date and promising and comprehensive one to start with. As most gaming ecosystems are connected online via the internet, players can permanent connect to the game and play, learn to know other players, adding new features, content and software etc. In contrast, the defense M&S systems are widely unconnected considering internet accessibility, or other users which results in missing opportunities regarding reuse, content sharing or adding knowledge.

Not unexpected, general major findings of this study are the heatmapping approach and their current results, as well as the note of "… missed opportunities for the defense industries to learn from the private gaming sector."

Paper (11) "Virtual Cockpit – Making Natural Interaction Possible in a Low-Cost VR Simulator"

training of pilots in classical high-fidelity but very expensive and only location-dependent flight simulators versus a VR-based flight simulation environment effective for location-independent, effective training. The paper describes the development of a VR-based tactical training simulation concept in which the pilot can hear and see his environment as well as feel and physically interact with the cockpit instruments at a highly realistic level regarding the training objectives. This Virtual Cockpit generates a high degree of immersion, which was confirmed by feedback of pilots training in such an VR environment. The paper summarizes as major benefits of this VR cockpit simulator its low cost and permanently improving technology, its visualization opportunities and variability of scenarios and cockpits, and its location independent usage. On the other side, the paper also notes limited resolution and missing natural interaction like haptic feedback as major drawbacks and challenges for technological advancements. Besides these challenges, the lower sense of presence and reality in VR, like to see your own hands, are still limiting factors. While these are not really limiting factors for general gaming, highest precision and precise alignment with reality are key factors for flight training.

The paper also reports on ongoing findings from tactical training of AH-64 pilots that are in general relevant for research activities on steady technological improvements, such as leap motion accuracy with respect to moving a virtual object or connections between the virtual user´s hands and a virtual object. The paper describes the physical, virtual and sensor layers of the developed Virtual Cockpit, as well as the methods used for the development and evaluation processes. Major results Virtual Cockpit project are the advantages of VR regarding flexibility, costs, and location-independence, but also the challenges like representation of realistic haptic feedback or VR related motion sickness.

Finally, in their forecast of future trends the authors note two other domains for promising applications: mission rehearsal and CD&E projects.

(YSA) "Multi Agent Reinforcement Learning Using Simulated Quantum Annealing"

Rightly, this presentation had received special attention as it was selected by the Symposium´s Programme Committee for the "NMSG Young Scientist Award". The awardee presented his forefront research on AI-based generation of COA´s in virtual worlds which can include besides a military scenario also urban warfare, e.g. in and around megacities.

For finding not only an acceptable but even the optimal solution in a decision supporting process in such a complex scenario, the author applies quantum tunneling. The proposed method also allows the generation of heatmaps as well as of optimal plans. Furthermore, it has the advantage that it is faster and offers higher

precision compared to other decision supporting techniques, and it includes learning capabilities. Using reinforcement learning techniques for adaptation of agent behaviour leads to quantum reinforcement. Versus classical reinforcement, this approach is much faster, requires less training steps and provides better COA results.

Emanating from the reported ground breaking methods applied and research results, future developments of decision supporting systems should at least consider these research results.

(Poster 2) describes by example of a supermarket use case, how effective training can be performed by simulation of autonomous multi-agent interactions where each agent can have different spatially defined goals. An agent´s path planning is processed on a strategic level. For agent stepwise decisions an operational model has been developed that uses an utility-maximizing discrete-choice framework.

(Poster 5) briefly describes "A Conceptual Model to increase Political-Military Fusion Exercise Events through Synchronous Distributed Wargaming". Objective of this poster demonstration is to provide a conceptual modelling approach which can embrace perpetual readiness and rehearsal at various levels of command for complex military-political situations by simulating interactions between numerous entities in the arena.

(Poster 6) "A Scalable Architecture for Rapid Terrain Analysis".

As data from terrain databases are a key prerequisite for all kinds of training and decision support systems, the poster describes the ARA software architecture which is dedicated to decompose terrain analysis tasks into subtasks in order to spread data and execution of tasks across a computer cluster. The software tools within this architecture allow job-dependent management, distributed and parallel processing, data transfer management and scalability. The poster presents an implementation of this approach and results of generation of a terrain data base of 1.2 TB source data.

4.2 Overall Evaluation of the Symposium

As mentioned in the introduction of this Technical Evaluation Report, NATO is facing rapidly changing scenarios or even new threats, like new political, military and technological challenges. Therefore, it is very important that NATO and especially NMSGs are keeping pace with scientific and technological advancements and upcoming innovative solutions. Also important are reports on gained experiences with specific M&S techniques and applications. In this regard, contributions of this Symposium consider major developments and trends by addressing research activities, advanced M&S developments and applications. The Symposium was especially focusing on conceptual and technological improvements for effective training and decision support and on exchange of experiences with M&S approaches and techniques in these important fields of M&S applications. A special emphasis was directed towards challenges in context of complex and flexible changing multi-domain scenarios.

The Symposium´s audience was given an excellent chance to share insight in and experiences with up-to-date scientific and technical advancements of M&S-technologies and -capabilities, in general, and with practical applications and experiences with use case applications. Besides some general advancements of M&S technologies, the audience received a deeper insight into the concrete and potential applications of Artificial Intelligence techniques in M&S-tools for training and decision support. As described in the previous sections, these AI applications offer new opportunities for simulation of "smart" human and system behaviour. A second focus of Symposium presentations was directed to the increasing importance of "Big Data" analysis – Data Analytics. In context of increasing volumes of collected and stored data - a result of rapidly increasing distribution and dispersion of sensor technologies - importance and benefits of applying data analytic techniques was expressed by several presenters and their papers. High quality and performance

of Data Analytics have to be seen as important prerequisite for gaining relevant input for machine learning methods, especially for reinforcement learning.

At first, I have to say, that theme, topics and presentations of this Symposium were very well selected by the Symposium organizers and the Programme Committee. In this regard, the five session topics perfectly addressed advanced technological opportunities for use in training and decision support tools and applications that can be of beneficial use and of interest for NATO forces and its members. In this regard, all presentations and the papers reflect concepts and use case experiences of enhanced M&S capabilities, but also of new challenges for future research and widespread applications.

Besides those advancements and positive experiences, several presentations also mentioned certain restrictions or constraints that have to be considered in context of some advancements and their intended use, such as:

- Acceptance of new approaches by M&S sponsors and decision makers;
- Users acceptance and objective evidences of beneficial usability;
- Resource and cost saving restrictions;
- Unknown, or unexpected events or threats as well as application constraints, e.g. like the current covid-19-related restrictions regarding education and training opportunities, or natural disasters like flooding for decision supporting M&S environments.

Finally, I have to say that most of the proposed methodological and technological advancements, experiences, and potential new M&S opportunities provide valuable insight for a wide audience, e.g. for others than just for international military forces within NATO. Even outside of NATO, major general findings and transfer of use case experiences of this Symposium could be shared for example with NGOs.

5.0 CONCLUSIONS

Overall, topics and substance of all Symposium contributions delivered an excellent overview on state-of-the-art of formal methods and technologies with respect to feasible and potential advancements in fields of M&S-based training and decision support. The Symposium´s presentations and their documentations offer very valuable results and important findings for military forces in the alliance, but also for a wider audience in and outside of NATO. The presentations addressed major hot topics currently discussed in the general M&S community, and most also provided novel M&S concepts and experiences of implementations and use case applications. A special focus was directed to M&S solutions for complex multi-domain operations which are of increasing importance e.g. for evaluation of situational awareness of hybrid warfare scenarios.

Overall, I was impressed by the substance and quality of all contributions – oral presentations, provided paper and poster documentations. This includes the organization of this Symposium, its moderation and administration. Around 90 attendees of the Symposium received a good overview of importance, feasibility and usability of major advanced modelling and simulation capabilities, often applicable for multiple purposes and not only limited to M&S training and decision support applications. It was obvious that the attendees and those virtually participating enjoyed the regained opportunities for manifold discussions in the audience and for networking and exchange of experiences in side meetings during the breaks as well as the Symposium organization by STO and the local organizers.

Looking ahead, regarding the permanent increasing capabilities and complexity of M&S-tools and their applications, and besides all the indisputable progresses and achievements presented in this Symposium, I strongly recommend to intensify research and activities on major arising problems:

- More research and efforts have to be taken which provide trustworthiness in quality, trust and usability of M&S-methods, -tools and -results that are delivered. Trainees and decision makers have to be convinced, that the provided M&S solutions are correct, traceable and usable for their intended purpose. That requires strict application of verification, validation and acceptance processes (VV&A), as well as use risk analyses – methods and international guideline for performing VV&A are available but too often neglected by M&S users as well as by military leadership.

- Potential negative side effects of new technology applications have to be carefully analyzed, such as for example results of AI applications for machine learning that are based on inductive methods like on artificial neural networks. This affects data analytics results, result interpretation and therefore validity of training data and their usability. Depending on the applied machine learning methods, confirmability of results could be not feasible even if results seem to be reasonable. That is also extremely important to consider in case of applications in M&S-based decision support systems.

- Another major concern relates to the overall increasing "systems complexity" risks. Nowadays, with steadily rapidly growing interconnectivity, use and complexity of "Systems-of-Systems" also in the military world, reflects also complexity of M&S-environments, -tools and -applications, as well as permanent increasing amounts of collected data. These ongoing trends urgently require new approaches for mastering and resilience of M&S-applications. From my point of view, basic concepts for mastering complexity of all kinds of systems is a key challenge for intensive research within NATO and for NMSG.

Finally, I like to thank the organizers for their hospitality, STO and the organizers and local administrators of this Symposium that has demonstrated its benefit for all attendees and for the NMSG-community in general. The organization as hybrid event was in my opinion successful, as it offered a wider community the chance to participate online at presentations and discussions without travelling. On the other side, it was again an excellent opportunity for exchange of experiences and for networking in presence. It can serve as a model for the organization of future NMSG-events like this one.

Appendix:

SCIENCE AND TECHNOLOGY ORGANIZATION

NATO MODELLING AND SIMULATION GROUP

MSG-184 RSY

12 October 2021

PROGRAMME

For the 2021 NATO MODELLING & SIMULATION GROUP (NMSG) SYMPOSIUM

Towards Training and Decision Support for Complex Multi-Domain Operations

		DAY 1 21 October 2021
09:00	KN1	**Keynote speech – Mr Auke VENEMA, Strategic Advisor NLD MoD, NLD STB Member**
		Session 1: M&S in support of Complex Multi-Domain Operations **Chair – Mr Wim HUISKAMP, TNO (NLD)**
09:30	1	**Modelling & Simulation and Data Science to support commander's white picture** COL (ret) Dr. Jan HODICKY, NATO HQ SACT JFD MSTT (NATO ACT)
10:00	2	**Getting Battle Labs ready for Multi Domain Operations: Main results and developments within the NLD MoD** MSc Lesley JACOBS, TNO Defence, Safety & Security (NLD) LTCDR Pascal ORDELMANS, Maritime Battle Lab (RNLN) (NLD) LTC Peter van ONZENOORT, CABL (RNLAF) (NLD) MAJ Peter GEURTS, IAMD Battle Lab (GBADC) (NLD)LTC Desmond LIBERG, Simulation Battle Lab (JIVC-KIXS) (NLD)
10:30		**Coffee Break**
		Session 2: Training Innovations **Chair – Mr Niels KRARUP-HANSEN, MoD DALO (DNK)**
11:00	3	**Withdrawn**

11:00	4	**Innovative automated analysis tools for After Action Review (AAR) using AI and modelling & simulation** Ms Anne-Gwenn BOSSER, MASA Group SA (FRA) Ms Ariane BITOUN, MASA Group SA (FRA) Mr François LEGRAS, MASA Group SA (FRA) Mr Hans TEN BERGEN, MASA Group SA (FRA)
11:30	5	**Live Air Training in a Synthetic Environment** Mr Michael JEBAUTZKE, Collins Aerospace (DEU)
12:00		**BREAK - 2 Posters introduced by a 5 minute pitch and with time allocated for discussion during the break.**
14:00	KN2	**The Virtual Command Post** **Experiencing today's technology in order to innovate tomorrows decision making** COL Mietta GROENEVELD, Director NATO Command and Control Centre of Excellence (NATO C2COE)

Session 3: Decision Support Innovations

Chair – COL Miro ČOLIĆ, Croatian Defense Academy (HRV)

14:30	6	**5th Gen Mission Planning: Integrated Systems and Algorithms** Ir. Antoine J.C. DE REUS, Netherlands Aerospace Center NLR (NLD) MSc. Jeanine I.D. VLASBLOM, Netherlands Aerospace Center NLR (NLD) Ir. Roy R.D. ARENTS, Netherlands Aerospace Center NLR (NLD)
15:00	7	**Deep Self-optimizing Artificial Intelligence for Tactical Analysis, Training and Optimization** Dr. Matthias SOMMER, Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport VBS, armasuisse Wissenschaft + Technologie (CHE) Dr. Oleg SZEHR, Dalle Molle Institute for Artificial Intelligence (IDSIA) - SUPSI/USI (CHE)
15:30		**Coffee Break**
16:00	8	**Geospatial Analysis for Machine Learning in Tactical Decision Support** Mr Maarten SCHADD, TNO Defence, Safety and Security (NLD) Mr Nico DE REUS, TNO Defence, Safety and Security (NLD) Mr Philip KERBUSCH, TNO Defence, Safety and Security (NLD) MAJ Ab DE VOS, JIVC/KIXS/Sie SIM (NLD)

Session 4: Novel Approaches

Chair – Mr Simon SKINNER, THALES UK (GBR)

16:30	9	**Opportunities for Military M&S to Capitalise on Gaming Technologies and Competences** Mr Andrew FAWKES, Vedette Consulting (GBR) Mr Matthew HEMSLEY, Vedette Consulting (GBR) Mr Douglas HENRY, Dstl (GBR) Mr Brian WARDMAN, Dstl (GBR)
	10	**Withdrawn**
17:00	11	**Virtual Cockpit – Making Natural Interaction Possible in a Low-Cost VR Ssimulator** MSc. Jeanine I.D. VLASBLOM, Netherlands Aerospace Center NLR (NLD) Ir. Antoine J.C. DE REUS, Netherlands Aerospace Center NLR (NLD) Ir. Roy R.D. ARENTS, Netherlands Aerospace Center NLR (NLD) Ir. Ronald F.W.G. VAN GIMST, Netherlands Aerospace Center NLR (NLD)
		NATO C2COE demo
17:30		
18:00		**End of Day 1**

		DAY 2 22 October 2021
09:00	YSA	NMSG Young Scientist Award Presentation MSc Paolo DE HEER, TNO Defence Research (NLD)
		Session 5: Decision Support Applications **Chair – Prof Andrzej NAJGEBAUER, Military University of Technology (POL)**
09:30	12	**Modelling and Simulation in NATO Federated Mission Networking** Dr J. Mark PULLEN, George Mason University (USA) Mr James KRAFT, National Defence Headquarters (CAN) Mr Ole Martin MEVASSVIK, FFI (NOR) Mr Christian WAGNER, Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (DEU)
10:00	13	**Simulation-Based Decision Support for the Logistic System of the German Armed Forces** Mr René KLEINT, ESG Elektroniksystem- und Logistik-GmbH (DEU) Ms Andrea GECK, ESG Elektroniksystem- und Logistik-GmbH (DEU)
10:30		**Coffee Break**
11:00	14	**From the game map to the battlefield – using DeepMind's advanced AlphaStar techniques to support military decision-makers** LTC Thomas DOLL, Army Concepts and Capabilities Development Centre (DEU) LTC Jan-Wilhelm BRENDECKE, Army Concepts and Capabilities Development Centre (DEU) Mr Matthias BEHM, AIRBUS Defence and Space GmbH (DEU) Mr Daniel KALLFASS, AIRBUS Defence and Space GmbH (DEU)
11:30	15	**Decision Support within Complex Subterranean Operations** COL (GS) Mag. Dr. Peter HOFER, Theresian Military Academy (AUT) Mr Julian EDER, IL - Ingenieurbüro Laabmayr & Partner ZT GmbH (AUT) DI Dr. Clemens STRAUSS, Institute for Military Geography (AUT)
12:00		**Panel session** **M&S Opportunities and Challenges in the context of Complex Multi-Domain Operations** Panel members (TBC)
12:30		**BREAK - 3 Posters introduced by a 5 minute pitch and with time allocated for discussion during the break.**
		Session 6: Towards Capabilities **Chair – Mr Bharat PATEL, DSTL (GBR)**
14:00	16	**Towards a NATO Reference Architecture for Joint Mission Training Through Distributed Simulation** Mr Tom VAN DEN BERG, TNO (NLD) Mr Wim HUISKAMP, TNO (NLD) Mr Henk JANSSEN, TNO (NLD) Mr Nico DE REUS, TNO (NLD)
14:30	17	**Towards a Modelling & Simulation capability for training autonomous vehicles in complex maritime operations** Dr Arnau CARRERA VINAS (NATO STO CMRE)

Dr Thomas MANSFILED (NATO STO CMRE)
Dr Pilar CAAMANO SOBRINO (NATO STO CMRE)
Dr Alberto TREMORI (NATO STO CMRE)

15:00 18 **How much is too much? Levels of A.I. Explainability within Decision Support Systems' User Interfaces for improved decision-making performance**
MSc Ghanshaam SEWNATH, Royal Netherlands Aerospace Centre NLR (NLD)
Mr Jur CRIJNEN, Royal Netherlands Aerospace Centre NLR (NLD)

15:30 TER **SUMMARY REMARKS by Symposium Technical Evaluator**
Prof Dr Axel LEHMANN

15:45 **End of Day 2**

***POSTERS**

DAY 1 (21 October 2021) Break Posters

1 **Withdrawn**

2 **Minds for Mobile Agents**
Prof Andrew HEATHCOTE, School of Psychology, The University of Newcastle (AUS)
Mz. Charlotte TANIS, Department of Psychology, University of Amsterdam (NLD)
Mr. Jonne ZOMERDIJK, Department of Psychology, University of Amsterdam (NLD) Dr
Tessa BLANKEN, Department of Psychology, University of Amsterdam (NLD) Assoc
Prof Dora MATZKE, Department of Psychology, University of Amsterdam(NLD) Prof
Denny BORSBOOM, Department of Psychology, University of Amsterdam(NLD)

3 **Learning analytics in military training simulation**
MSc Linsey ROIJENDIJK, TNO Soesterberg (NLD)
Dr. Heleen PENNINGS, TNO Soesterberg (NLD) Dr.
Esther OPRINS, TNO Soesterberg (NLD)
Dr. Karel VAN DEN BOSCH, TNO Soesterberg (NLD)
Dr. ir. Jikke REINTEN, TNO Soesterberg (NLD)
Ir. Peter LANGESLAG, TNO Den Haag – Waalsdorperweg (NLD) Drs.
ing. Armand VINCENTIE, Defensie Materieel Organisatie (NLD)

DAY 2 (22 October 2021) Break Posters

4 **Autonomy Studio Tool: a virtual studio for multi-domain complex operations simulation**
Mr Jérôme HABONNEAU, THALES DMS France SAS (FRA)
Mr Bruno QUELLEC, THALES DMS France SAS (FRA)
Mr Matthieu BAUCHE, THALES DMS France SAS (FRA) Mr
Ludovic MARCHAL, THALES DMS France SAS (FRA) Mr
Florian DIGNE, THALES DMS France SAS (FRA)

5 **A Conceptual Model To Increase Political-Military Fusion Exercise Events Through Synchronous Distributed Wargaming**
MAJ Stephen NELSON (NATO ACT)
COL (ret) Dr Wayne STILWELL, Stilwell Technology and Robotics, LLC (USA)

6 **A scalable architecture for rapid terrain analysis**
Ir. Frido KUIJPER, TNO Defence, Safety and Security (NLD)
Dr Ruben SMELIK, TNO Defence, Safety and Security (NLD)

Appendix

For the 2020 NATO MODELLING & SIMULATION GROUP (NMSG) SYMPOSIUM

Towards On-Demand Personalized Training and Decision Support

to be virtually held on **22-23 October 2020**

		DAY 1 22 October 2020
13:30		Introduction
13:40		**Keynote speech –** Dr Bryan WELLS, NATO Chief Scientist
		Session 1: Personalised Training **Chair** – Mr Wim HUISKAMP, TNO
14:00	1	**On-Demand Skills Training to Support Regular Continuation Training for Fighter Pilots** Dr Jelke VAN DER PAL [introduction], Royal Netherlands Aerospace Centre Dr Armon TOUBMAN, Royal Netherlands Aerospace Centre Mr Jur CRIJNEN, Royal Netherlands Aerospace Centre
14:30	2	**Feasibility of Performance-Based Training Programs for Combat Aircraft Pilots** Dr Eirik Løhaugen FJÆRBU, Norwegian Defence Research Establishment Dr Guro Kristin SVENDSEN, Norwegian Defence Research Establishment Dr Jelke VAN DER PAL, Royal Netherlands Aerospace Centre
15:00	3	**Virtual Training using Real Applications** Mr Ian COX, SEA Mr Angus LAURIE-PILE, SEA
15:30		**BREAK - 3 Posters with 5 minute pitch each***
		Session 2: Towards Capabilities **Chair –** Mr Bharat PATEL, Dstl
16:00	4	**Data Farming Services (DFS) for Analysis and Simulation-Based Decision Support (Invited presentation)** LTC Stephan SEICHTER, Bundeswehr Office for Defence Planning Dr Gary HORNE, Johns Hopkins University Applied Physics Laboratory
16:30	5	**EuroSIM Constructive Training System for CBRN Incident Response Training** Dr Jamie ENGLAND, Riskaware Ltd Dr Martyn BULL, Riskaware Ltd
17:00	6	**Simulation as a Service (SaaS) for Decision Support & Training** Dr David Matthew CULLEY, Improbable UK Mr Philip John CAVANAGH, Improbable UK Mr Richard WARNER, Improbable UK
17:30	7	**Virtual C2ISR for NATO intel training** LTC (ret) Matthew MARTIN, L3Harris Technologies, Inc.
18:00		**End of Day 1**

DAY 2
23 October 2020

Session 3: Decision Support
Chair – Mr Bharat PATEL, Dstl

13:30	8	**M&S decision making support for Crisis Disaster Management & Climate Change Implications** COL Dr Orlin NIKOLOV, Crisis Management and Disaster Response Centre of Excellence (CMDR COE) CDR Navy Harold PIETZSCHMANN, Future Planning Office of the Bundeswehr Dr Rachid EL ABDOUNI KHAYARI, IABG Dr Konstantinos TSETSOS, Bundeswehr University Munich COL Plamen MILANOV, CMDR COE LTC Kostadin LAZAROV, CMDR COE
14:00	9	**Wargames for Command Decision Support** Mr Iain McNEIL, Slitherine / Matrix Games
14:30	10	**Application of Artificial Intelligence Based Simulations for Military Logistics Supply Network Decision Making** Mr Christopher BEVELLE, The University of Manchester Dr Richard ALLMENDINGER, The University of Manchester Dr Darminder GHATAOURA, Fujitsu
15:00		**BREAK - 2 Posters with 7 minute pitch each***

Session 4: Novel Approaches
Chair – Mr Wim HUISKAMP, TNO

15:30	11	**Artificial Intelligence for After-Action Review** Dr Stephen LUCEK, NSC
16:00	12	**The Assessment and Generation of Evidence for XR Approaches in Training** Mr Mayowa OLONILUA, Dstl Mrs Samantha BLACK, NSC Mrs Eleanor FORREST, Bright HF Limited Prof Dr Petra Saskia BAYERL, CENTRIC
16:30	13	**Sensor Simulation Microservice** Mr Steven WEBSTER, Planned Systems International (PSI) Dr. Robert KEWLEY, simlytics.cloud Dr. Joseph MCDONNELL, Trideum Corporation Ms Susan HARKRIDER, U.S. Army
17:00	14	**Assessing & Selecting AI Pilots for Tactical and Training Skill** Dr Jared FREEMAN, Aptima, Inc. Mr Eric WATZ, Aptima, Inc. Dr Winston BENNETT, U.S. Air Force Research Laboratory
17:30	TER	**SUMMARY REMARKS by Symposium Technical Evaluator** Prof Axel LEHMANN, Bundeswehr University Munich

*POSTERS

DAY 1 (22 October 2020) **Break Posters**

1 **Adaptive Agent Behaviour for Personalized Training**
Mr Romy BLANKENDAAL, TNO
Dr Karel VAN DEN BOSCH, TNO
Mr Rudy BOONEKAMP, TNO
Mr Tjeerd SCHOONDERWOERD, TNO

2 **USAF Performance Evaluation, Tracking and Feedback**
Mr Eric A. WATZ, Aptima, Inc.
Mr Brad PFEFFERLE, Aptima, Inc.
Dr Winston BENNETT, US Air Force Research Laboratory

3 **Lessons learnt from Implementing Modelling & Simulation as a Service (MSaaS)**
Dr Keith FORD, Thales UK

DAY 2 (23 October 2020) **Break Posters**

4 **Contemporary Gaming Architectures & Ecosystems: Utilisation and Application in Military M&S Training and Decision Support Systems**
Mr Thomas W D EVANS, Staffordshire University
CPT (hon.) Stephen J. WEBLEY, Staffordshire University
Mr Anthony J. HADLEY, Staffordshire University
Mr Andy FAWKES, Thinke Company Ltd

6 **A Proof-of-Concept Demonstration of Dynamic Synthetic Environments in Distributed Simulation**
Mr Neil SMITH, DSTL
Mr Arno GERRETSEN, Royal Netherlands Aerospace Centre
Dr Ruben SMELIK, TNO
Dr Kevin LY VAN, Thales