Technical Evaluation Report

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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 consider 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 transatlantic alliance of 30 nations has to be prepared for a wide range of multi-national and joint operations of air, land, maritime, cyber and space forces. This requires that all NATO force elements, 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 methodological and technological opportunities (tools), this requires improved agility and collaboration among nations, especially regarding data and information exchange capabilities, effective multi-national collaboration platforms.

On the other side, besides already applied and available experiences with modelling and simulation 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), gamification with serious games, or virtual, augmented, mixed reality tools (VR, AR, XR) offer new opportunities but also new challenges. Major challenges concern less offered functionalities of the above mentioned technologies, but usability, user-acceptance and cost-effectiveness for their intended application purpose. Beside these challenges, it is obvious, that their use contributes to the tremendously increasing amounts of data, increasing software complexity and system-of-system implementations.

2.0 THEME OF THE SYMPOSIUM

As summarized in the introductory remarks, NATO and its alliance are confronted with requirements to support cost-efficient and resource-saving a wide range of missions, changing scenarios and new threats. At the same time, advanced methods like for “big data” analyses or of artificial intelligence offer together with advanced technological developments in fields like VR/AR/MR or parallel, distributed or cloud-computing new opportunities for enhanced simulation-based training and decision supporting environments. In regard of urgent requirements for NATO forces mentioned in the introductory remarks, this Symposium focused especially on simulation-based personalized, adaptive training opportunities, and on use of on-demand –

faster than real-time – decision supporting systems. Effective personalised training and on-demand decision supporting tools are important steps forward for military forces of all nations and of the alliance. In this regard, the organizers of this Symposium selected the theme "Towards On-Demand Personalized Training and Decision Support".

3.0 PURPOSE AND SCOPE OF THE MEETING

The purpose of this Symposium was to provide an overview of current state-of-the-art and trends of advanced methods and technologies in the military domain, in general, and specifically for simulation-based support of advanced education and training opportunities, as well as for decision support. In this regard, the scope of the Symposium´s program structure in the Appendix):

- Personalized Training
- Decision Support
- Towards Capabilities
- Novel Approaches

Importance of On-Demand Personalised Training: Already now, but even more required in the future, NATO forces have to be prepared for quick operational readiness in sometimes rapidly changing scenarios and for new threats. Therefore, greater agility and interoperability will be required across the Nations for multi-national operations, to come together quickly and to be prepared and trained for close collaboration. Taking also into account updated or new operational guidelines, system components etc. as well as advanced training methods, need increases to immerse and train the individual warfighter in a variety of scenarios, together with other individuals and increasingly in human-machine teams to be qualified at a high-level of readiness to rapidly response to known and unknown future threats. For various reasons, such as cost- and resource-saving requirements or the current pandemic, but also advanced educational methods and techniques applicable in off- and on-line tools, enable training and assessment of the trainees performance at any time and at any location.

Importance of On-Demand Decision Support: Increasingly Nations and NATO commands want to continuously be on-alert to identify new or resurgence of old threats, and want to be able to make the right decision on the course of action to take well before escalation to a conflict or to aid decisions during operations. This requires to use real world data - which will be increasingly available with spreading applications of sensor technologies - together with the available modelling and simulation capabilities to project the outcome from emerging threats, as well as test and optimise the course of action needed to mitigate those threats. Time constraints require, that real data collection and analyses, model development, simulation and testing of the actions will have to be done in faster-than-real time to assess the threats and optimise the actions. Therefore, on-line modelling and simulation based operational decision support tools are required to support our strategic and tactical command staff as part of the command and control system.

Directed Towards Capabilities: The nature of current and future requirements for training and decision support will mean that on-demand distributed capabilities based on modelling and simulation will be critical to ensure our forces are prepared, ready, and have the right tools, to overcome whatever threats they may encounter now or in the future. Developing technologies that can provide us with a rapid and agile modelling and simulation capability, to represent current and future scenarios will be essential. Delivering these at the point of need whilst interacting with other national components and NATO organisations at on-demand pace will be essential and time-critical to ensure our forces are ready to rapidly response and make the right decision for success, not only in terms of successful outcome after a conflict but 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 an on-demand distributed modelling and simulation capability to meet the needs of training and decision support. Therefore, advanced education and qualification methods, technology trends, as well as current developments in the commercial world particularly from the Gaming and ICT sectors, including mobile and social media sectors have to be considered and exploited in the military context. How these developments and trends can be integrated together with those developed by defence should now be the focus for NATO S&T community. It will also be essential to ensure that the modelling and simulation capability is designed to be enduring and continuously improved to keep pace with new methods and technology trends. Otherwise they will loose the comparative advantage gained in preparing own forces to their adversaries.

The Symposium was opened by a short keynote speech of NATO Chief Scientist, Dr. Brain Wells. He expressed the recognition and appreciation of STO and MSG activities by NATO leadership and its forces at all levels. He mentioned that in many ways scientific and technical contributions of these organisations are important for future developments of planning, decision making, acquisition, education and training processes and supporting tools. The keynote was followed by forteen paper and five short poster presentations organized according to the above mentioned four sessions during the two days. Programme and schedule of the Symposium are listed in the Appendix.

4.0 EVALUATION

For evaluation of the Symposium´s scientific and technical results, its contributions in form of papers, posters and discussions, different points of view 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) methodology, technologies and applications for personalized training and for decision support are subject of this evaluation in subsections 4.1.1 and 4.1.2). On the other hand, a summary of novel or advanced methodological or technological approaches which should be also considered for strengthening NATO military forces in general, are summarized in subsections 4.1.3 – 4.1.4). Finally, in section 4.2, this technical evaluation report concludes with major observations, an overall evaluation and in section 5 with some suggestions for future consideration by NATO, especially by STO and MSG for future planning of multi-national M&S-Symposia or technical activities.

4.1 Summary of Papers and Posters

At first, to structure this report thematically and for the ease of citation, in the following subsections presentations are grouped according to the thematic topics of the Symposium by their paper or poster numbers.

4.1.1 Papers and Posters on Personalised Training

The following list of presentations includes all contributions focusing on personalized or adaptive training concepts, simulation environments and use case applications:

(1) On-Demand Skills Training to Support Regular Continuation Training for Fighter Pilots
(2) Feasibility of Performance-Based Training Programs for Combat Aircraft Pilots
(3) Virtual Training using Real Applications

(Poster 1) Adaptive Agent Behaviour for Personalized Training
(Poster 2) USAF Performance Evaluation, Tracking and Feedback

In view of rapidly changing military scenarios, threats, but also for mission planning or training of operational processes or new weapon systems, NATO forces have to be prepared and trained for operational readiness under given constraints such as cost and resources efficiency. In this regard the above listed 5 contributions reported on advanced approaches and experiences of performance-based personalized training. The first two papers (1) and (2) report on consecutive approaches for personalized and adaptive training concepts for performance-based and individualized training missions for F-16 fighter pilots, and along the same context poster (2) describes a performance evaluation and tracking system for the US air force.

Paper (1) reports on an approach to retain performance-based tactical, as well as procedural and flying skills. The purpose of a retention model is to predict for an individual trainee those skills that have to be retained after some time of non-use. Challenges that have to be considered in the model are the assessment of skills by measurement of a wide range of variables that have to modelled, and the high dimensionality of the required data. The paper describes a retention model for pilots to restore their proficiency gaps with minimal training time, costs and means.

As the design of a single retention model for any type of trainee seems to be not realistic, the authors propose instead a model architecture that offers models applicable to specific tasks depending on the availability of data from students. The video game Space Fortress allows to study acquisition of combinations of cognitive, motor, and procedural skills to process a specific task. An online adaptive instructional system was developed that teaches the game, and that imposes the trainee not to play the game for a proposed time – the retention interval. After that time the user has to perform a retention test. Currently the retention model is tested by use of synthetic data. The more real data is available, some relationships between performance of participants with respect to retention intervals will be obtained by use of regression techniques. The plan is to use machine learning by using a recurrent neural networking model for the prediction of tasks to be trained. From each trainee for every executed task performance indicators are measured, like test scores and physiological data. These measures along with some – if available – personal data are planned as input for the predictive model. The future plan is to validate this retention modelling approach with realistic F-16 training data.

As performance-based training has high demands for flexibility of individual training and of training programs. Paper (2) reports on a collaborative project of NLR and NAF for an adaptive performance-based training (see Paper (1)) optimizing training programs with respect to a set of competence requirements. Feasibility of currency-based requirements have been obtained by simulation experiments with the virtual TREFF simulator for training of combat aircraft pilots of the Norwegian Air Force (NAF). With the TREFF simulator feasibility of planning training programs for the pilots under consideration of restrictions like limited resources, stochastic events and scheduling of training missions. The competence-oriented, performance-based training approach described in Paper (1) enables the development of training programs adapted to individual needs of a trainee. That requires a high degree of flexibility for training systems and a challenge for scheduling of individual training missions. Paper (2) considers in addition the challenge and feasibility of incorporating real-time adjustments of such an individual personalized training program as visionary goal. That means, in a first step, personalized training should be optimized according to required performance and individual trainee´s needs. When successful, adaptive training can be added. Therefore, empirical data regarding typical decay of skills has to be available. Studies show that e.g. psychomotor skills of physical tasks are memorized longer than knowledge of procedural skills. In addition, cognitive skills and motivation are important factors to be considered for retention. As a test case, Paper (2) considers 2 different aspects for planning mission training for pilots:

(a) Competence-based training under consideration of a variety of missions, competencies, complexity factors and retention intervals. 2 types of missions are considered: part-task missions

and tactical missions.

(b) Currency-based training program: Contrary to (a), an ordered list of specific missions is planned by use of an OR-tool (COMFORT) that creates a currency-based training program, which means it sequences execution of training missions (live as well as simulations) evaluated by a cost function. Test case-based evaluation of benefits of currency-based training!

Paper (3) considers maritime training scenarios for operators and maintenance personel, as training with real hardware-software systems is quite often not feasible and also expensive. While especially costs of hardware equipment can be very high for training purposes it can be replaced by virtual and interactive 3D models of that hardware and displayed by means of virtual, augmented or mixed reality (VR/AR/MR) and software functionalities can be hosted and emulated by a Virtual Machine running on a standard PC. The paper proposes an enhanced training solution that offers training scenarios in which emulated and real hardware / software components or systems can be part of the simulation environment. This environment includes an emulation engine with a VR/AR interface for the trainee, a signal interface to respectively from real hardware devices as well as to and from software signals via a Virtual Machine Infrastructure. Major benefits of such an approach include that emulated as well as real hardware and software components can be combined within a virtual environment. The personel to be trained can see, walk around and work with the equipment they have to operate to maintain. Other benefits of such a simulation environment are that planned but currently not real existing hardware / software components can be already included for training purposes, and a trainee´s training or refresher progress can be tracked and considered for further training.

Poster (1) describes a training environment with virtual players implemented by software agents. The implementation of these agents delivers a real-time adaptive agents behaviour depending on the trainee´s behaviour. That enables adaptation of agents to the competence level of the trainee. Regarding other approaches for agent-based training simulation environments for pilots, in section 2.4 of this report, paper (14) should be considered, which describes a novel agent-based approach for training pilots in combat together with adversary “smart AI-pilots”.

As already mentioned at the begin, Poster (2) describes a performance evaluation and tracking system (PETS) for the US air force. This PETS traces and offers feedback from training missions for trainees, as well as for instructors and decision makers.

In brief, major contributions on the Symposium´s topic of personalized adaptive training are:

- development and results of a retention model for pilots personalized, effective training
- a simulation-based training platform with real and emulated hardware / software components and use of XR-technologies for maritime training
- real-time adaptive agents representing “AI pilots” as virtual players
- a performance evaluation and tracking system approach

4.1.2 Papers and Posters on Simulation-Based Decision Support

The following list include contributions on simulation concepts and environments for support of decision making processes:

(4) Data Farming Services (DFS) for Analysis and Simulation-Based Decision Support (Invited presentation)
(6) Simulation as a Service (SaaS) for Decision Support & Training
(8) M&S decision making support for Crisis Disaster Management & Climate Change Implications
(9) Wargames for Command Decision Support

(Poster 3) Lessons learnt from Implementing Modelling & Simulation as a Service (MSaaS)

With the permanent increasing performance of computing systems including parallel and distributed architectures, as well as with permanently increasing capabilities of modelling methods and simulation techniques, very powerful and effective simulation environments are available. These developments enable the design of increasingly complex models often with a huge amount of input, state and output parameters which consequently require a huge amount of input data for simulation applications. For decision supporting simulations for example, instead of real and validated data quite often only uncertain, vague or even missing information has to be represented in these models which results in searching the best optional solutions by analysis of huge ranges of state spaces. In these cases, for data farming experimentation specific algorithms for efficient goal-directed Design of Experiments (DoE) are used for goal-directed and effective analysis of huge state spaces.

The invited presentation (4) covered major activities and results of MSG-155 and MSG-088 (Data Farming in Support of NATO) like assessment of data farming methodologies and a use case for decision support in case of optional cyber defence operations. The simulation was implemented with the tool PAXSEM from Airbus. Besides a summary of results of this use case considering highest vulnerability and most efficient cyber defence operation for protection of nodes in a network, the presentation also reported experiences with the flexible and efficient application of microservices and container technology (Docker containers) in this context.

In accordance with rapidly increasing application and experiences of cloud-services and Software-as-a-Service (SaaS) environments, Modelling-and-Simulation-as-a-Service (MSaaS) is seen as an efficient approach for resourcing cloud-based M&S-platforms and -services for implementation of complex simulation scenarios. Paper (6) and Poster (3) are also reporting on MSaaS applications and experiences.

Synthetic environments are a multi-domain approach to model complex training and planning scenarios at various levels of detail, e.g. of a battlefield, for different applications and for multi-stakeholders usage. It can offer shared views and understanding for decision makers from different perspectives which share common responsibilities, e.g. political, military or economical point of views. In paper (6), the authors present Improbable´s platform for development of synthetic environments that incorporates a framework for development of massive multi-player computer games (SpatialOS) which enables SaaS for support of decision making processes as well as for training applications. In this synthetic environment, multiple domains and influences e.g. from weather, military forces, communication capabilities, population features and behaviour, traffic can be represented and modelled. As described in the paper, major technical benefits of this platform are handling of communication and synchronisation between models and other components, as well as distributed and load-balanced computing is taken care of by this platform. Its applications are especially beneficial for large-scale simulation applications. As the system is implemented using open standards, models, simulations, or artificial intelligence and machine learning functionalities can be integrated. The Common data Model (CDM) is used as schema for data exchange to facilitate interoperability between models and other functional components within the platform. Technical assets of the Synthetic Environment ecosystem include e.g. weather, communications, social media, military forces etc. Experiences or examples for concrete applications, e.g. of a use case, are not presented.

Without detailed background information, Poster (3) presented an MSaaS architecture offering multiple services e.g. for repositories, cloud provision and services, procurement, or security. Neither technical details nor lessons learned are documented.

The same MSaaS concept is subject of poster presentation (6): “A Proof-of-Concept Demonstration of Dynamic Synthetic Environments in Distributed Simulation”. Emanating from an MSaaS-simulation architecture proposed by MSGs 136 and 164, the poster shows a synthetic environment introduced by MSG-156. The presentation shows the conceptual architecture that was used by MSG-156 for representation of a

trafficability scenario influenced by weather situations, which served as and was used for proof-of-concept implementation. This poster also doesn´t provide any results.

Two other presentations of this Symposium aimed at supporting commanders decision making. While paper (8) describes a technical platform supporting decision making in case of crisis or desasters, paper (9) is focused on a IT-based platform for wargaming exercises.

Paper (8) summarizes essential results of MSG-147 "M&S decision making support for Crisis Disaster Management & Climate Change Implications" works regarding a technical platform for decision support and training in context of CAX. In its introduction the paper points out that military simulation environment for precise simulation of a range of disasters are not available on the market. Only a few singular models exist with the required accuracy, e.g. for flooding. Another key problem is, that disaster and crisis management varies significantly in and between member states, and responsibilities are often even shared between government institutions. Besides lack of comprehensive and standardized NATO crisis management processes, there are no M&S-approaches and -platforms available in the Alliance for common and collaborative education programs, training or for risk analysis and decision supporting tools. Therefore. purpose and objective of the MSG-147 project was to develop a reference architecture and demonstrate a technical platform that enables prompt, reasonable and effective tests of Crisis/Disaster and CCI Response plans. The approach taken was based on 3 pillars: (a) development of a disaster risk management process as prerequisite and followed by (b) the development of a platform for disaster response operation planning. Pillar (c) to offer a model repository with mathematical disaster models and a „disaster engine". The „disaster engine" consists of an data input interface, a disaster modelling component executing mathematical models from the repository, and an output interface). Furthermore, a decision-making support software component and a filtering and distribution software component for filtering and distributing the relevant response actions that should be taken. The model repository can be connected in an HLA architecture with a federation of simulation models. A Disaster Federation Object Model was specified to enable simulation federations for data exchange of disaster events in an HLA-environment, like for flooding, wildfire and toxic clouds. A simulation-C2 system gateway facilitates information transfers between (military and civilian) simulation and c2-systems and vice-versus. In addition, a standard operating procedure (SOP) data base was developed including some SOPs from SEEBRIG (South Eastern Europe Brigade). Finally, but without any further detail, the development of an AI-based selection mechanism for automatic SOP recommendations was mentioned.

While current training environments and supporting tools are primarily focusing on single soldiers like pilots, infantry, drivers or gunners, efficient and effective training opportunities "advanced" wargaming platforms for commanders are missing. Today´s military computer-based wargaming can be effectively applied as training platform supporting military leaders to exercise decision making processes on battlefields as addressed by presentation (9). In view of new or rapidly changing complex scenarios or unexpected events those advanced training opportunities are urgently required supporting a commander´s decision making capabilities. COA planning tools are available but don´t deliver results (MoE´s). "Classical" wargaming for commanders is manual, expensive to arrange as it takes groups of experts and time to attend and therefore with only very few opportunities for training, and not scalable. For effective training, trainees need a holistic view of complex scenarios, which requires state-of-the-art and innovative IT-support for realistic representation of battlefield dynamics, such as visualization capabilities, repositories with a variety of services and tools for planning, simulation, games etc. Presentation (9) describes such a flexible, scalable training platform but only at a high level. As no paper was delivered, no technical details or experiences can be described or evaluated.

In brief, major contributions on the Symposium´s thematic focus on decision supporting approaches are:

- Applications of and experiences with data farming for decision support
- Applicability and efficiency of MSaaS platforms e.g. for crisis management

- General benefits of model repositories
- Efficiency and effectiveness of digital wargaming
- Synthetic environments for training and decision support

4.1.3 Papers and Posters on Towards Capabilities

The following list include those presentations that are subject to the following review of this subsection Towards (M&S) Capabilities:

(5) EuroSIM Constructive Training System for CBRN Incident Response Training
(7) Virtual C2ISR for NATO intel training
(10) Application of Artificial Intelligence Based Simulations for Military Logistics Supply Network Decision Making

Another focus of the Symposium was put on contributions reporting on advanced or new simulation capabilities for NATO forces. In this context, three paper presentations proposed advanced capabilities for training opportunities in case of CBRN events, for intelligence, surveillance and reconnaissance situations, as well as for decision support in case of military logistics supply networks.

In view of this goal, Paper (5) titled “EuroSIM Constructive Training System for CBRN Incident Response Training” presents a EuroSIM prototype training system for exercising handling actions in case of Chemical, Biological or Radiological threats and events – right now not including Nuclear events. The training platform offers interfaces for trainers, commanders as decision makers, and trainees. Including MSaaS capabilities, the distributed modelling environment enables visualization of simulated ground-truth and actual status of casualties in case of a synthetic CBR event. The scenario presented demonstrates how a commander can track GPS positions of trainees, their exposure and health status depending on their locations. For commander training, it also enables the commander to direct trainees as first responders according to the actual situation. First responder trainees receive chemical sensor data by an app, can see their simulated individual health status, and can use personal protection equipment for treatment of casualties. From a technical point of view, the modelling service is a Java Spring Boot Service for modelling of dispersion cloud, casualty dose and health status, incident and entity controller integrated in the company´s Riskaware HEART framework. This framework including a time step manager enables time stepped execution of system dynamics at least as fast as real time. Web app back ends for managing the scenario as well as for observation of scenario dynamics are also Spring Boot services. These apps offer different views to the trainer (having full control of the model´s capabilities) and the commander whose view is limited to real world observations. The framework also offers DOCKER containers for deployment on server or in the cloud. Finally, the paper includes a detailed description of a use case and concludes with options for EuroSIM´s further development.

Paper (7) on “Virtual C2ISR for NATO intel training” addresses at first an arising training problem for NATO forces: development of capabilities for processing, exploitation and dissemination (PED) of intelligence /surveillance/reconnaissance (ISR) data through NATO intelligence centers and through national contributions. At this stage, no standardized capabilities or intelligence-dedicated mission simulation platforms exist within NATO for cross-alliance effective training of IRS analysts or intelligence forces.

The Virtual ISR Training Application (VISTA) proposed and presented in this paper offers training opportunities for personel involved in processing, exploitation and dissemination (PED) of ISR data and for different job skills. VISTA prototype is compliant with cybersecurity and network standards, can be connected to operational networks and interface with other simulation tools for integrated network training. VISTA also integrates sensor simulation modules for production of required sensor data. Therefore, VISTA can generate sensor data instead of missing real data which can be used by other operational tools or other

virtual training systems. This offers training opportunities for a wide range of job trainings, for either specific individual job training or for team training. The VISTA prototype was tested by participation in NATO-ISR-exercise Unified Vision in 2018 (UV 2018). Due to a lack of live ISR data, VISTA produced synthetic data for different scenarios to stimulate NATO ISR networks. This synthetic data could be streamed to all players and enabled the exercise team to perform and test different techniques, tactics and procedures. To summarize: The VISTA concept provides scalable, scenario-based capabilities to generate synthetic c2-ISR data for individual as well as for team PED training across different operational networks. Its prototype application has been proven to be very effective in the UV 2018 test case. Plans for implementation of advanced capabilities include automated image recognition providing information on sensor positioning, or target ID, embedded mission rehearsal for C2 teams planning and assessment of effectiveness, as well as adaptive learning regarding adaptation of a trainee´s performance to ensure positive training results.

Paper (10) "Application of Artificial Intelligence Based Simulations for Military Logistics Supply Network (MLSN)" proposes a synthetic environment for decision support of military logistics. Military logistics networks have the same challenges like commercial ones, e.g. with respect to balancing resource requirements and time constraints. But they differ significantly from commercial ones regarding sudden, unexpected changes during a mission that can happen at any time and with uncertain frequency. Supporting the selection process for MSLN missions under these conditions, Paper (10) proposes the deployment of a synthetic environment employing gaming technologies, decision science methods and AI-based simulations. This synthetic environment including human-machine-teams provide a digital twin of the real world that can be used to process all kinds of data, can discover opportunities, and provide realistic visualization for enhancement of the decision making process. The paper provides insight in the modelling concepts and methods that are applied. For example, agent-based technology is used to represent non-player characters, and finite state machines and behaviour trees are applied to generate reactive agent´s behaviour. Goal-oriented action planning is another concept which allows agents to communicate within the synthetic world and to plan goal-directed actions based on the agent´s current state. Agents apply "complex AI-methods" like reinforcement learning for planning or navigation. From a technical point of view, agents are programmed with the AI planner of Unity game engine which applies a trial based heuristic tree search algorithm – an important method to explain and verify AI behaviour. For test purposes and illustration, the paper also describes three typical logistic use case scenarios (vehicle breakdown recovery, routing problem for water distribution and human-machine-teaming).

In brief, as major contributions on the Symposium´s thematic focus on decision supporting approaches are:

- Distributed simulation platform with MSaaS for training and decision support in case of chemical, biological and radiological events
- Training platform VISTA for virtual intelligence, surveillance and reconnaissance M&S
- Synthetic environment with human-machine teams represented as digital twin of a real world logistics scenario for decision making

4.1.4 Papers and Posters on Novel Approaches

The "Novel Approach" session with its four paper and one poster presentations provided an excellent view on applicability and use case experiences of innovative technologies for simulation-based training and decision support by application of various AI methods, VR/AR/XR tools, specific sensor simulation or gaming techniques:

(11) Artificial Intelligence for After-Action Review
(12) The Assessment and Generation of Evidence for XR Approaches in Training

(13) Sensor Simulation Microservice
(14) Assessing & Selecting AI Pilots for Tactical and Training Skill
(Poster 4) Contemporary Gaming Architectures & Ecosystems: Utilisation and Application in Military M&S Training and Decision Support Systems

In context of their research of efficient methods for support of decision making, documented in paper (11), the authors report on their development of a novel approach for AI-based analysis of large solution spaces to find "good" solutions, in case of "Artificial Intelligence for After-Action Review" to find a "good" plan. The methodological approach of this development includes a Mission Planner which applies stochastic AI optimisation methods of Genetic Programming (GA) and Simulated Annealing (SA). Application of GA delivers a pool of solutions for a specified problem including measures for quality and fitness of these solutions, while simulated annealing considers single solutions (plans). The proposed approach checks the diversity of plans resulting in "good" results in correlation to the number of decision options of a decision maker. As this approach requires the definition of a similarity measure of plans, the paper includes a short review of those and applied a modified Cosine technique. As use case for test purposes, a wargame simulation for simulated brigade level operations on a battlefield in a test scenario of second world war was selected, wherein AI generated the operations of red and of blue forces in the wargame. Intermediate results generated by the analysis tool during live simulation show the correlation between diversity of plans and the proposed plan options for the virtual commander.

Paper (12) on "The Assessment and Generation of Evidence for XR Approaches in Training" presents two new frameworks for applicability and quality of Virtual, Augmented, and Mixed Reality (VR, AR, and MR) analyses – briefly labelled as XR-analyses for education and training (E&T). Within these frameworks a portfolio of evidences is offered for exploitation of XR technologies supporting defence E&T opportunities. The concept described combines a two-fold approach: A qualitative assessment framework, and a trial planning framework. The first one defines criteria and scores for quality evaluation based on suitability and robustness of data collections, on rigour of the analysis process, and on purpose and coherence of reports analysed. Each aspect is scored on a 7-point scale translated to an overall qualitative classification of strong, moderate or weak. Presentation of the final qualitative assessment finally results in one of 9 Evidence Readiness Levels. The second framework, the trail planning framework, provides templates for frequently used trial designs and gives guidance for development of trial protocols that can deliver evidences of high quality (functionality and usability, trainees perceived usefulness and satisfaction, assessment of intended benefits). Besides description of the proposed approach and frameworks, no XR-assessments from uses cases are presented.

Presentation (13), titled in the Symposium´s Program "Sensor Simulation Microservice", addresses urgent requirement of efficient integration of sensor performance for simulations. Along with the rapid increasing availability of a wide range of sensor technologies, the authors mention as current problem of sensor / target model representation in simulation their often required off-line processing and manual import into a simulation. Often analysts depend on static configuration data and performance characteristics which might be also outdated. Therefore, this presentation (paper was not available) proposes in accordance with the Modelling & Simulation as a Service (MSaaS) concept an implementation of Sensor as a Service part of a service-oriented simulation infrastructure. Major expected benefits are greater variability and faster exploration of sensor / target technologies within virtual, constructive simulation and in games. This research is targeted on synthetic training environments that include capabilities for simulation of sensors performance for weapons, navigation, situational awareness etc. Such a simulation infrastructure provides also opportunity for generation of synthetic data which can be applied for training and verification of machine learning algorithms. The ppt slides document in detail the NATO concept, its basic architecture and applied techniques, implementations as well as an example.

Paper (14) on "Assessing & Selecting AI Pilots for Tactical and Training Skill" addresses resource-saving approaches for fighter training are an always an important issue. As Subject-Matter-Expert (SME) are

always a scarce resource, presentation and Paper (14) reports on an alternative, a generic concept for pilots combat training which replaces the need for human SMEs participation as advisories in exercises or simulations by AI-implemented pilots. In this concept, combat opponents are replaced by smart agents with tactical expertise. The paper reports on the results of this project which include beside the development of eight different architectures and implementations of smart agents by eight firms, the development of an agent testbed. For implementations of these AI pilots, different modelling methods and AI techniques were applied ranging from rule-based production systems, state-transition nets, mathematical cognition models to reinforcement learning algorithms. The paper describes the eight different implementation approaches of the firms to represent smart pilots, that are able to fight very robust in a range of combat scenarios. These agents were developed, respectively trained, to generate and coordinate tactical actions regarding different types of advisories in 72 scenarios. The paper also includes a description of the testbed architecture, a system-of-systems Distributed Interactive Simulation (DIS)-architecture which can also integrate multiple Computer-Generated-Forces systems (CGFs) and a Next Generation Threat System (NGTS). Assessment of AI-pilots behaviours is based on annual assessment events, where each year one of the 72 scenarios is selected, announced in advance to the competitors, and assessed by SMEs. Examples for AI-pilot scores are presented in the paper.

(Poster 4) “Contemporary Gaming Architectures & Ecosystems: Utilisation and Application in Military M&S Training and Decision Support Systems” gives an overview about reasons and potentials applying gaming technologies for education and training military forces. On the one hand, computer game technologies offer a variety of new opportunities for education and training, such as use of graphics for realistic visualization, VR / AR / MR, human-machine-interaction, retrospective recording or playback of missions, and performance scoring. On the other hand, as described by the poster, the community of gamers is rapidly increasing and familiar with these technologies and commercial products. Therefore, applications of computer gaming methods and services can enlarge an MSaaS-based simulation ecosystems wherein gaming services are provided.

In brief, major “take-aways” from these presentations in context of the Symposium´s thematic focus on novel approaches that should be considered are:

- AI-based optimized mission planning
- Evidence measures for quality and applicability of XR-technologies in military education and training
- AI- / agent-based methods for implementation of virtual smart players in simulation
- Potential benefits of including gaming techniques and
- sensor simulation as services in MSaaS platforms

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. In regard of geopolitical, military and economical developments and constraints, contributions of this Symposium consider these trends by current M&S developments, research activities as well as by challenges of advanced education, training and decision supporting M&S-tools and -platforms. The Symposium´s audience was given an excellent chance to share insight, experiences and understanding of state-of-the-art M&S-tools, platforms and use case applications, as well as of technological advancements and innovations of digitalization, in general, which offer new opportunities but also challenges.

In this regard, theme, topics and selected contributions of this Symposium are subject of the following overall evaluation. At first, I have to say that the theme of the Symposium and its four session topics addressed perfectly urgently required improvements as well as new opportunities for training and decision support concepts and tools that are of great interest for NATO forces and its members. In this regard, all presentations and their documentations reflect most of these requirements and constraints as well as new opportunities for application of advanced methodologies and technologies in M&S.

Reviewing at first, from a technical perspective, new or advanced methodological and technological opportunities for training and decision supporting systems were presented. Especially the following advanced design principles, modelling methods, technologies and platforms for effective M&S-based applications were addressed in the Symposium´s presentations:

- Service-oriented M&S architectures (MSaaS), e.g. for development of trustful, often used, basic M&S services or components;
- parallel and distributed simulation methods, such as for data farming, including efficient algorithms for design-of-experiments, for providing in a timely manner useful sets of decision options;
- Several simulation platforms that can be also applied for synthetic data generation, especially in case of missing real data;
- A variety of AI-techniques for development of “smart” solutions, ranging from rule-based production systems, reinforcement algorithms applied as machine learning technique, mathematical cognition models, or stochastic optimization with simulated annealing and genetic algorithms. It should be also mentioned, that some contributions just use the general term “AI-based method” instead of describing concrete the applied method or class of implemented algorithm;
- Different types of agent-based approaches like reactive and deliberative agents, for representation of artificial players in simulation;
- Development of a retention modelling approach for trainees for application in personalized, adaptive training environments;
- VR/AR/MR devices and their applications, such as in virtual simulation environments for advanced or even new training opportunities, but which need still more test applications and evaluations regarding efficacy or usability experiences e.g. with respect to movement sickness;
- Synthetic environments offering opportunities for representation of multi-domain scenarios for training as well as for decision support.

On the other hand, almost all contributions took into account major restrictions and constraints that have to be considered by these advancements in context of the intended use of the proposed solutions, as well as in the addressed application domains, such as:

- Decision makers and users acceptance and usability
- Resources and cost saving restrictions
- Unknown, or unexpected application constraints or threats, 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.

It should be also mentioned that most of the proposed methodological and technological advancements and experiences provide also valuable insight for others than international military forces and should be shared, such as for simulation-based training and decision supporting processes of NGOs.

5.0 CONCLUSIONS

Overall, topics and substance of all contributions of this Symposium delivered an excellent overview on state-of-the-art formal methods and technologies with respect to potential advancements in fields of M&S-based education, 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 NATO. The presentations addressed major hot topics currently discussed in the M&S community, and most also provided experiences of use case applications across military forces from land, air, maritime, and cyber application domains.

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 online-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.

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 undertaken which provide trustworthiness in usability and quality of M&S-methods, -tools and -results delivered. Trainees and decision makers have to be convinced, that the provided M&S solutions are correct and validated for their intended purpose. That requires strict application of verification, validation and acceptance processes too often neglected.
- Potential negative side effects of new technology applications have to be carefully analysed, such as for example motion sickness by use of XR-technologies, or backtracking of reasoning processes and proposed decision options generated by use of “AI-methods”.
- Another major concern relates to the overall increasing “systems complexity” risks. Risk analyses methods and approaches, including measures for quality assurance are major challenges that need more focus of the M&S community and leadership.

Finally, I like to thank the organizers and the administrators of this online-Symposium that has demonstrated its feasibility and benefit for the attendees and for the NMSG-community under current restrictions. It can serve also as a model for the organization of future events like this one, which could be also organized as hybrid events which would allow more networking opportunities for those who can meet in person. To offer side chat rooms besides plenary online presentations could also motivate those who can only attend online.

Riemerling /Germany, November 2020 **Axel Lehmann**

6.0 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