NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

EXECUTIVE SUMMARIES

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NATO STO Collaborative Programme of Work Technical Reports 2022 Book of Abstracts

January 2022

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INFORMATION

The document contains the collection of Abstracts of the technical reports published within the Collaborative Programme of Work by the NATO STO in 2022. Documents are arranged in chronological order according to the date of publication.

The reference number of each document is an active link pointing to the document in the STO publications database on the website.

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STO-TR-IST-ET-104 Physical Unclonable Functions (PUFs) in Military IoT

This study focuses on the applicability of Physical Unclo nable Functions (PUFs) in military Internet-of-Things (IoT) context. PUFs can be considered as a hardware-based source of entropy due to uncontrollable physical characteristics of certain manufacturing process details. This entropy source is in some contexts very cheap and has great promise in hardware security. However, current implementations are somewhat vulnerable especially to machine learning attacks. Despite of the vulnerabilities, PUFs offer cheap and easy solutions for lower security environments, and are already used commercially. In the comparative study performed here, PUFs are likely to shrink the existing IoT attack surface – this implies the fact that even though ideal PUFs seem hard to achieve, the current state of IoT security welcomes any and all security solutions for the better. In the military context, each use case should be validated by comparing the security model to the capabilities of the particular PUF implementation. Most promising military application areas would be to secure the IoT technology within logistics, smart equipement, medical care, situational awareness (sensor data), blue-force tracking and mission ICT services, in this order. The technological uses cases revolve around cryptographic key-storage, authentication, service provisioning and tamper-evidence of IoT hardware

STO-TR-IST-146 Electromagnetic Environment Situational Awareness

Military radio systems operate in a congested and contested electromagnetic environment. The NATO STO established the Research Task Group 069 in order to take charge of the IST-146 project on Electromagnetic Environment Situational Awareness (EME SA). The project aims at evaluating the operational benefits of EME SA for NATO in line with the Electromagnetic Spectrum Strategy and to evaluate the Radio Environmental Map (REM) technology. Several military scenarios and vignettes are considered for the study. The operational analysis establishes the importance of Electromagnetic Spectrum C2 integrated with other C2 processes. The description of the EME SA/REM data sources, models, and representation is done. Key user benefits are highlighted. An EME SA/REM reference architecture based on the Internet of Things(IoT) is proposed. The relationships between the REM, REM Users, REM Things, and REM devices have been validated through the project vignettes. Proposals for possible evolutions of the electromagnetic operations and spectrum management within NATO are made. A roadmap in three steps (five, ten and twenty years) is proposed. A demonstration was foreseen where these of EME SA/REM enabled understanding an interference situation through visualization and to de-conflict by dynamically re-assign frequencies. The demonstration was cancelled due to the COVID-19.

STO-TR-HFM-276 Human Factors and ISR Concept Development and Evaluation

The NATO HFM RTG-276 Panel titled Human Factors and ISR CD&E was established to identify Human Factors (HF) issues critical to effective Joint and ISR operations within a NATO operational level Headquarters (HQs). More precisely, the goals of the HFM RTG-276 were: 1) To gauge current knowledge about HF research in the ISR CD&E process; 2) To identify critical HF to effective JISR operations within a simulated NATO JISR operation; 3) To further validate a model of organizational effectiveness for understanding, explaining, and measuring different aspects of HF issues in JISR operations; and 4) To make recommendations regarding improvement of education and training of NATO and partner countries' militaries for ISR CD&E coalition operations. Broadly, the findings revealed that HF issues are an important component of effective and efficient JISR operations. It was discovered that the federation and coordination between nations can be improved by improving the way information is shared and through the reduction of coordination needs during the execution of operations. The research showed that individual, organizational, and cultural issues are important for improving the effectiveness of ISR operations. An understanding of the various dimensions of data quality is important for information quality management during ISR operations. Finally, the researchers used observational data and interviews within one French PED cell to provide further validation of the theoretical framework used to guide this research.

STO-TR-IST-157 Human Considerations in Artificial Intelligence for Command and Control

Over recent years, a growing recognition of the role for humans in the use of Artificial Intelligence has led to major developments supporting human machine teaming. IST 157 has leveraged the work of other research groups to apply and update previous findings to C2 and decision making processes. The work of IST 157 will directly benefit 3 functional concepts of the ACT Command & Control focus area: Cognitive Computing & Advance Analytics, AI to support human sense making, and AI at the effector edge. Relying on a team made of representatives from seven nations (Bulgaria, Canada, France, Germany, Turkey, United Kingdom and USA) and three NATO bodies (ACT, C2COE, NCIA), IST-157's achievements covered two simultaneous and complementary fronts, meant to eventually converge: • A comprehensive desk study/paper oriented work. • The development and experimentation of a tool during a major NATO exercise (STJUJA20). Although the STJUJA20 exercise was cancelled because of the COVID-19 pandemic, the experimentation of the ANTICIPE tool, developed by academic and industrial partners of the RTG will be performed during the STJU-22 exercise as the IST-157 team decided to start a new research project, IST-192, that will specifically focus on this experimentation.

STO-TR-MSG-163 Evolution of NATO Standards for Federated Simulation

The overall objective of NATO MSG-163 was to evolve and promote NATO standards for Federated Simulation through work on five (5) sub-objectives: 1) Maintenance and update of the NATO Allied Modelling and Simulation Publication 04 (AMSP-04) (NATO Education and Training Network Federation Architecture and FOM design) standard delivered as NATO AMSP-04 Ed B Draft for NATO Modelling and Simulation Group (NMSG) approval and publication by NSO. 2) Maintenance and update of the NATO Integration, Verification and Certification Tool (IVCT) delivered as Open Source Software. 3) Update of the Concept of Operations (CONOPS) for High-Level Architecture (HLA), STANAG 4603, and the Certification Service. Delivered as updated 'Draft CONOPS' for NMSG MS3 approval. 4) Support to 'HLA Certification Entity' as 'Accredited Test Inspectors' (ATI) for 'HLA Certification' provided by members of MSG-163. 5) Improve awareness in regard of these before mentioned products and disseminate results delivered as papers, presentations, lectures, and workshops.

STO-TR-AVT-359-Part-I Impact of Hypersonic Operational Threats on Military Operations and Technical High Level Requirements Phase 1

Military capabilities able to fly with hypersonic speeds are in the focus of interest for basically all military planners and procurement agencies, and policymakers. A fundamental understanding of what such capabilities can actually achieve and what is likely not is crucial. This is especially true for identifying what might be needed to counter them and to maintain a credible deterrence posture in the future without wasting scarce defence funds. This report commences with analysis of open source, acclaimed international hypersonic developments and capabilities, their general technical background and limits and highlights options to counter hypersonic threats. The report will be structured around the OODA loop (Observe, Orient, Decide and Act, by John Boyd) with OOD in Part 1 and Act in Part 2. Furthermore, supporting fields of interest like M&S(Modelling and Simulation), ETEE (Education, Training, Exercise and Evaluation) or Automation and their relevance for hypersonics will be highlighted as well..

STO-TM-AVT-ET-209

MHM Technologies – Enabling Early Adopters

The Exploratory Team AVT-ET-209 on “MHM Technologies – Enabling Early Adopters” was active during one calendar year, from 1st January 2021 until 31st December 2021 with a total of 25 people being formally appointed, from ten different nations and two NATO bodies. The aim of this activity was to determine the way forward, based on the previous results achieved. The first focus was on reaching out to ‘early adopters’ of MHM or new end users. Secondly, the focus was placed on the needs and solutions for NATO organizations, such as NSPA. Finally, the objective of the ET was to seek for expansion within NATO nations. The main output of this activity is: 1) The submission of a Technical Activity Proposal (TAP) for a Research Lecture Series on the implementation of MHM. This TAP was approved in November 2021. 2) An increased interest on MHM within NATO nations. Belgium, France, Poland and Sweden were added to the team together with a key player at the NATO level: NSPA. 3) The feedback from the group on the AOP-4844 NATO Handbook for MHM resulted in the formation of a new Custodian Working Group (CWG) under the umbrella of AC/326 SG/B for improving the current document.

STO-TR-AVT-236

Next-Generation NATO Reference Mobility Model (NG-NRMM) Development

A unified (generic) tactical missile kinetic performance model (code) and database for early screening and basic layout of a missile propulsion subsystem was developed by the AVT-236 task group for use by procurement agencies, system providers and propulsion manufacturers. The model provides consistency and interoperability in defense planning studies and can eliminate barriers for collaboration within NATO. This advanced simulation tool can simulate missile fly-outs along a given trajectory from short range to long range with different rocket and ramjet propulsion concepts under equal conditions and modeling standards. It allows the user to create basic design of a tactical missile with a choice of different propulsion subsystems. It contains propulsion subsystems that are typically used for tactical missiles (solid rocket motors, throttle able ducted rocket), as well as some propulsion systems (gelled propellant rocket, hybrid rocket and solid fuel ramjet) that are good candidates for future use. Thrust vector control (TVC), air intakes, trajectory modelling, and smoke classification (according to STANAG 6016) are further propulsion-related aspects treated in the unified generic model. The report is divided in two parts. Part I describes the software with the embedded unified generic model and its (sub)models for the above mentioned propulsion systems. Part II is the manual for the user to get familiar with the operation of the code, the user interface, the error messages, etc.

STO-TR-AVT-327 Standardization Recommendation (STANREC) Development for Next-Generation NATO Reference Mobility Model (NG-NRMM)

The primary work of the AVT-327 committee was to achieve the publication of the Standardization Recommendation (STANREC) covering modelling and simulation (M&S) related to the Next-Generation NATO Reference Mobility Model (NG-NRMM). That goal was achieved and the document was developed and promulgated in the form of Allied Modelling and Simulation Publication – 06 EdA, V1. STANREC 4813 is the cover letter formally recommending its use in mobility modelling among the allied nations. The content and purpose of this final report of the AVT-327 committee is to collect the lessons learned and future directions of research necessary to mature, verify, and validate the technologies and methods recommended in AMSP-06 and, if necessary, suggest the scope of a future revision.

STO-TR-SCI-224-Part-II EO and IR Countermeasures Against Anti-Ship Missile

New EO/IR anti-ship missile threats have advanced image processing capabilities seekers that enable significantly improved guidance capacity and also Counter-Countermeasure (CCM) functionalities. Real time numeric image processing gives the possibility to implement many different criteria. Consequently, new imaging seekers have available very clever capacities in terms of scene analysis and flare discrimination. Such a technological gap will induce some drastic changes in the current methodologies used both for the missile threat expertise and for the Countermeasures (CM) techniques elaboration and especially about flare modelling. For old centroid tracker, global intensity was generally enough to compute angular error. At the opposite, new imaging seekers are able to analyse several morphological criteria like roughness, aspect ratio, radiance distribution, etc., for CCM improving. These new performances require enhanced flare modeling to analyze impact on guidance performances. So IRCM against new imaging seekers should be evaluated regarding two problematic. Firstly, modeling capabilities must be clearly improved to get a realistic physical rendering; secondly IRCM tactics must be generic because the counter measure strategy doesn’t address a specific threat but generic CCM concepts. So the simulation must be flexible with high modeling capabilities to cover a wide spectrum of threats. The aim of SCI-224 is to elaborate a common scenario from generic data in different national simulations to compare methodologies and results against different seeker models. This report deals with models and simulations used by each nation to implement the common scenario and exploit the run results.

STO-TR-HFM-290 Advances in Military Personnel Selection

This report explores topics within the umbrella of personnel selection, to identify current trends, challenges, and developments in the field. The focus is on three areas that have significance in today's defence context: integrity, online/computerised testing, and diversity. With respect to integrity, this report provides insight into the history of integrity testing in the military; examines the current state of integrity testing practice and research across participating nations; summarizes commercial integrity tests and emerging approaches to assessing integrity; and provides a framework for defining integrity in the military for the purposes of its assessment in military personnel selection. On the topic of online/computerized testing, it examines the selection testing practices of participating nations, in addition to exploring psychosocial factors, testing security challenges, options for online test administration, and the benefits to personnel selection that can result from technology implementation. In the area of diversity, the concept of diversity, fairness and inclusivity considerations in personnel selection practices, and neurodiversity initiatives within defence are explored. Drawing upon the current state of practice and research, this report hopes to raise awareness of and provide guidance on topics that deserve consideration in military personnel selection.

STO-TR-HFM-291 Ionizing Radiation Bioeffects and Countermeasures

The HFM-291 RTG on "Ionizing Radiation Bioeffects and Countermeasures" (active 2017 – 2021) addressed the medical challenges of NATO military defensive operations that could be conducted in a Nuclear/Radiological (NR) environment as well as scenarios such as the Radiation Dispersal Devices (RDD, dirty bomb), Radiation Exposure Devices (RED, e.g., hidden radioactive source in a train) and Improvised Nuclear Devices (IND). This RTG dealt with high-level, and to a lesser extent, with low level radiation issues. Chapters addressed: i) Status reports from participating nations related to radiobiology, ii) High-level radiation exposure (research on biomarkers of exposure (dose) reconstruction and effect prediction (e.g., ARS), medical countermeasures, and modelling), iii) Research on low-level radiation (represented by one nation's contribution only); iv) Collaborations among RTG participants; and v) RTG deliverables: two workshops (NATO StTARS workshop on software tools for triage of the ARS) and developing the base of a NATO App for improving risk communication in a RN event, comparing radiation exposure risks with daily life risks (CRRis). The final chapter lists scientific articles published by RTG members dealing with the RTG's activities. Each peer-reviewed publication represents an independent validation of NATO research, reflecting its significance. This productivity appears surprising given the reduced number of participants and nations for almost the whole RTG life-cycle

STO-TR-MSG-SAS-178 Using Simulation to Better Inform Decision Making for Warfare Development, Planning, Operations and Assessment. A New Approach to Sharing Models and Simulations Across the Alliance

Modelling and Simulation (M&S) has been successfully used to support decision-making within NATO for decades. M&S is used in many areas, including, advanced operational planning, capability-based planning, capability and concept development, and to support experimentation and wargaming. M&S takes many forms, from large complex Campaign Simulations designed to be used repeatedly over many years, to simulations built quickly for a single purpose. M&S is a key tool for NATO, but it can be costly to develop and maintain, and requires specialist expertise that is in short supply. M&S is an area where the Alliance's collective capabilities and willingness to collaborate should give NATO the advantage.

STO-TR-HFM-305 Synthetic Biology for Defence

Exploiting synthetic biology for defence will provide powerful enabling military capabilities over the next two decades and focus across NATO countries is now shifting towards demonstrating the viability of bio-products in operational settings. The current pipeline of new technologies leveraging synthetic biology will provide access to a breadth of resources, reduce operational costs, and increase operational flexibility. Synthetic biology clearly offers valuable applications for defence but the pace of the technological advances enabled by biotechnologies is outpacing the speed at which biosafety and biosecurity measures can be developed and implemented to prevent malicious use of resulting products or processes. Coordination between NATO nations over the next twenty years will be crucial to ensuring the security of our forces and protection of member states against harm that could be propagated through misuse of synthetic biology advances.

STO-TR-IST-ET-111 Knowledge representation and reasoning – a review of the state of the art and future opportunities

This report presents the findings of NATO Information Systems Technology (IST) Exploratory Team 111 (ET-111) regarding the status of Knowledge Representation and Reasoning (KRR). Knowledge representation is the expression of knowledge that is computer-tractable, able to be reasoned over, and exploitable – especially in the age of big data. This report provides a technical introduction to the field of KRR. The capabilities of knowledge systems are discussed, as well as how they can be created, and how they may then be applied to real-world military problems. The distinction is made between KRR ('symbolic' AI) and machine learning ('sub-symbolic' AI), along with a consideration of how the two approaches can be complementary. We discuss some of the challenges for NATO member nations, and how KRR can influence these areas. We present specific examples of knowledge representation including the Multilateral Interoperability Program (MIP) Information Model (MIM), the Rich Event Ontology (REO) and the Defense Intelligence Core Ontology (DICO). Moreover, we review areas of research including causality, explainability, and trust in KRR systems. Finally, we discuss implications for NATO, and present our key recommendations for future work involving technical activities and exploratory teams.

STO-TR-AVT-301 Flowfield Prediction for Manoeuvring Underwater Vehicles

AVT-301 was initiated to improve the insight into the influence of grid density, grid set-up, numerical settings and the user on the prediction of naval ship hydrodynamics. The current work was based on research performed in earlier AVT RTGs. In this report, the background of the project, the test case, definitions, the active members in the team and the solvers used are described and the outcome of the studies performed by the AVT-301 RTG are presented. Numerical predictions were performed for a generic underwater vehicle (the BB2 hull form) and the results were compared to experiments. The main conclusions drawn from the studies are given. The detailed analysis of the results show that good agreement with the experiments can be obtained by the state-of-the-art tools used within AVT-301. Depending on the intended application, guidelines regarding grid set-up and grid resolution have been derived. The lack of experimental uncertainty values makes it impossible to quantify modelling errors in the computations. It is concluded that more targeted (and high-fidelity) experimental data for flow field validation is needed to further advance CFD flow predictions for challenging conditions involving separated flow (e.g., shear stress distribution data for rudder stall and detailed data of junction flows).

STO-TM-IST-ET-106 Data Hiding in Information Warfare Operations

Data hiding technique and technology is a vast area of military implementations that has confirmed its usefulness and innovative features especially in military communications and cyber defense scenarios. A new dimension of communication layer – the Hidden Data Layer has been discovered and migrated into military systems as a new threat and challenge. Nowadays it seems that complementary technology to cryptology – Data Hiding – is mature enough to be represented as a new IST activity. Thus, we have secret transmissions with the use of cryptology and hidden transmission with the use of steganography. At the moment, existing papers in the literature of the subject contain the following descriptions of innovative communication equipment, e.g., a steganographic filter to remove hidden transmission; a steganographic router; numerous methods of data hiding in multimedia based on the digital watermarking; and new steganographic methods in radio communication (radio steganography) and also in computer networks (network steganography). At the same time, there are numerous descriptions of methods for analyzing and detecting hidden data and also for identifying attacks carried out with the use of hidden transmission.

STO-TR-AVT-294 Towards Improved Computational Tools for Electric Propulsion

This document provides a summary of the activities of the NATO AVT-294 RTG. After a brief overview of the importance of computational tools for EP to accelerating the transition of plasma thruster technology, the bulk of this work focuses on new areas of emphasis which should be pursued with particular focus on synergies with larger emerging technological trends including massively parallel computing and machine learning. The document also provides a series of recommendations to assist decision makers in targeting additional investment areas to maximize benefit of computational tools for EP to advancing NATO space capabilities.

STO-TR-SAS-139 NATO Analytical War Gaming - Innovative Approaches for Data Capture, Analysis and Exploitation

SAS-139 was a research task group that ran between 2018 and 2021, named NATO Analytical War Gaming – Innovative Approaches for Data Capture, Analysis and Exploitation. Its aim was to conduct research to advance NATO's capability for Analytical Wargaming – that is wargames that are designed to rigorously address a specific research question or set of questions. Members conducted research into artificial intelligence and automation for wargaming, how to improve wargame rigor by using experimentation principles, mitigating for bias, and pairing established Operations Research and Analytical methods to wargame design and analysis. The research group also investigated and demonstrated the use of technology for wargaming, and established a NATO Wargaming Community of Interest. Work was disrupted due to the COVID-19 pandemic, but SAS-139 found an opportunity to research and learn early lessons from the exponential rise in Distributed Wargaming. Each chapter of this report has been designed to be read as a stand-alone paper so readers can skip ahead to what interests them the most.

STO-TR-MSG-165-Part-II Incremental Implementation of NATO Mission Training through Distributed Simulation for Joint and Combined Air Operations. Reference Architecture

This document described the MTDS Reference Architecture (RA), providing a source of reference and direction regarding the design, development and implementation of a synthetic collective training environment for MTDS. The MTDS RA is aligned with the NATO C3 Taxonomy and provides a framework and structure of which the content (Architecture Building Blocks (ABBs) and Architecture Patterns (APs)) can continuously be improved and enriched as demand and insights evolve.

STO-TR-MSG-165-Part-I

Incremental Implementation of Mission Training through Distributed Simulation for Joint and Combined Air Operations

NATO needs an MTDS capability to provide mission training and operational assessment of air and C2 systems in all core airpower roles, including Maritime Air, Land Air and JISR (AGS, UAV) components. This joint extension to Air MTDS represents a huge challenge in scenario scalability and variability. Technically new standards will be required to interface operational C2 databases to scenario generators, additional Tactical Data Links are to be considered, LVC federation, Cross Domain Security solutions, federation execution supervision and mission planning and debriefing tools will also be required in order to support operational NATO exercises. The MSG-165 objective is the incremental implementation of an initial MTDS capability in coordination with relevant MTDS exercises.

STO-TR-HFM-ET-184

C2 Capability Lifecycle Management

Doctrine and concepts for C2 have changed over the past three decades. We now find ourselves in an era of constant competition, hybrid warfare and rapid technological development. Nonetheless, compared to developments in other areas of warfare, such as weapon technology, platforms, etc., C2 practice, including current training and education, organisation, and employment of enabling technology, is largely the same as twenty years ago. This report explores reasons why C2 transformation may have failed or stalled and explores potential solutions. A meta-solution may be needed; i.e., adopting a “life cycle perspective” that shapes all factors that contribute to C2 capability. The feedback aspect of lifecycles will also need to be embraced, including organisational learning and the adaptive management of current and emerging C2 capabilities. The research concludes that there is significant similarity in the issues faced by the individual nations taking part, suggesting that there are forces at work that transcend national differences. We propose that a NATO and partner nation-wide response to these challenges would be beneficial in helping to guide, stimulate, and drive national and coalition responses. In practice, this entails the creation of programs focused on making C2 a capability to be governed. To assist in this endeavor, it is proposed that an RTG create a standard of practice for C2 transformation that ensures our military organisations assess success and failure, learn from these, and use the feedback to make improvements. The emphasis would be on sustaining healthy organisational cultures and identifying mitigations to the barriers for change. NATO nations need to agree on much of the above and to share lessons learned about success and failure. The proposed RTG could create a framework through which NATO militaries can improve the change/transformation approach so that future efforts at C2 change will yield greater and longer-lasting effects.

STO-TR-HFM-ST-335

Biotechnology, Human Enhancement and Human Augmentation: A Comprehensive Overview of its Topical Content

The HFM-335 Specialist Team (ST) was tasked to scan across biotechnology, human enhancement and augmentation and generate an overview of this emerging and disruptive technology area. The report presents a high level overview of the key applications of biotechnologies and human enhancement / augmentation as they relate to military capabilities, and an indication of their current and projected Technology Readiness Levels (TRLs). This report provides a vision that advancements in biotechnology and its convergence with computational sciences, microelectronics and artificial intelligence is fuelling the bio-revolution that can be leveraged for military applications. In short, the future of warfare will likely leverage advances in biomaterials, bioelectronics, synthetic biology, and biosensors to enable warfighter capabilities, either by improved training regimes, optimized nutrition, personalized performance augmentation or by genetic modification, etc. Other biotechnological advances will enable a more informed, integrated warfighter, such as human-machine interfacing to reduce the manpower needs to control complex machinery, enhanced decision making, improved diagnostics (to counter CBRN threats), and advances in medicine. Biotechnology has significant implications for military capabilities. NATO will need to keep abreast of the biotechnological advances and how they can best be applied for defence. This report summarizes such capabilities and their impacts on warfighter systems, military medicine, warfighter performance and force protection. It highlights the security and compliance issues underlying the ethical use of biotechnologies. This report will also inform future research areas within the STO Panels, creating an opportunity to maintain the Alliance's technological edge.

STO-TR-SET-263 Swarm System for Intelligence Surveillance and Reconnaissance

Future NATO Joint Forces will incorporate autonomous and semi-autonomous ground, aerial and sea platforms to improve the effectiveness and agility of Forces. These autonomy-enabled systems will deploy as force multipliers at all echelons from the squad to the brigade combat teams. The RTG SET-263 “Swarm System for Intelligence Surveillance and Reconnaissance” analyzed operational and system issues of swarm systems which could facilitate their integration in current battlefield tactical systems from both operational, system, and technological point of views. This final report provides a High Level Reference Architecture for Swarm-centric Systems for ISR (SS4ISR) which integrates and extends the outcomes of the previous two years of the SET-263 Research Study. The reference architecture addresses Operational issues (operational scenarios, key capability goals and supporting capabilities, and relevant SS4ISR operational activities); System issues (key system services provided from SS4ISR); Technologies (current and foreseen standards and algorithms for achieving expected system capabilities); and System-level Interoperability design guidelines for the adoption of swarm system in joint/multinational coalition and integration with legacy ones. The report also illustrates the main relationships between Operational and System issues via a set of relationship matrixes and describes the set of research topics addressed by the SET-263 Research Study: Detection and Tracking; Human-Swarm Interaction; Swarm Control and Navigation; Robot-Robot Interaction; Localization and Mapping in Swarm Systems; Data Exchange; and Networking.

STO-TR-SET-250 Multidimensional Radar Imaging

Limited resolution, self-occlusion effects, geometrical limitations and some difficulties in the image interpretation strongly affect the performance Automatic Target Recognition (ATR) systems when using Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR) images. Some of these limitations are due to the use of classical monostatic, singlechannel, single-frequency and single-polarization systems, as they are simpler to build and handle than complex systems as well as cheaper. The use of additional information on targets, such as response to variations in frequency, polarization and aspect angle has been seen to provide more robust methods for the detection and recognition of targets. SET-250 has aimed to study, develop and validate radar imaging algorithms that exploit multi-dimensional radar data to obtain more accurate and richer radar imagery. SET-250 has also planned and carried out large trials in Spadeadam (GBR), where four airborne radar imaging systems simultaneously acquired multi-channel, polarimetric, multi-frequency and multi-aspect radar data. The data gathered represents today a unique dataset that can be used to test and validate multi-dimensional radar imaging systems and target detection/recognition systems that are based on multi-dimensional radar data. SET-250 has successfully demonstrated that multi-dimensional radar imaging systems outperform traditional ones in terms of image resolution, target detectability and content richness, which are essential ingredients to boost system detection and recognition performances.

STO-TR-HFM-286 Leader Development for NATO Multinational Military Operations

NATO faces operating environments that are increasingly dynamic, technologically advanced, and Volatile, Uncertain, Complex and Ambiguous (VUCA). Through the NATO alliance, member nations and allies can respond to future operational challenges by building shared purpose and mutual assurance, by collaborating and sharing resources and risks, and by stimulating each other's innovation and creativity. However, to realise these advantages, NATO will need leaders capable of crossing cultural as well as geographical boundaries to bring their organisations together. They will require highly developed social, cultural and ethical abilities to build the trust and understanding needed to succeed as an alliance. This report presents an integrated competency framework for NATO leader development that defines the key skills required for the effective leadership of multinational military operations. It is also intended to help align individual nations' leader development programmes which independently engage in preparing their future leaders. Alongside the framework, this report identifies and examines key areas for effective multinational leader development. The challenges of managing and exploiting situational, technological and ethical complexity are explored alongside the skills required for enabling inclusive and creative cultures and building effective relationships to deliver and maintain an enduring NATO alliance for the future.

STO-TR-MSG-189 AI augmented immersive simulation in Training and DM Course of Actions Analysis

The MSG-189 Technical Report describes the Reference Architecture of an innovative framework aiming at integrating emergent technologies into an advanced simulation environment used for Training and support for Decision Making in the military field. Technologies such as Artificial Intelligence, Machine Learning, Big Data, immersive AR/VR/XR, Cloud computing and Virtualization techniques are integrated with each other and provided as services in a typical simulation architecture based on the MSaaS paradigm. This integration produces a distributed and open Ecosystem in which the services, managed by the framework, use these emergent technologies "by design" to provide the necessary tools for advanced Training and support for Decision Making. In many cases, this approach allows for a more efficient use of the functions, in some other cases it radically changes the way of approaching problems and provides new solutions through the functionalities of the framework. The Reference Architecture identifies the building blocks needed for the services, describing their tasks, internal and external relations, without however going into details on their realization. The outcome of the MSG-189 specialist team is intended as a first step for future working groups that, starting from the results described in the final report, can deeply define target architectures functional to specific areas.

STO-TR-IST-163 Deep Machine Learning for Cyber Defense

The main goal of the Research Task Group (RTG), Information Systems Technology (IST) 163 activity is to consolidate the NATO-wide knowledge in the field of deep ML and cyber defence, identify the gaps between civilian solutions and military needs, and collaborate with other NATO nations to use data processing, share data and pursue the transfer of the most promising technologies and applications to the military domain. The RTG activity examined the civilian and military needs and solutions including gaps and existing cyber defence techniques. The RTG examined these techniques in alignment with the National Institute of Standards and Technology (NIST) guidelines as guiding factors to compare how the current practices compare to the standards with an assessment of limitations and challenges. The research task group discussed sharing methods and models and the state of the art for sharing data across NATO nations. The technical report scrutinises the intricate utility of DML, practical implementations as well as open challenges. The Research Task Group comprises experts across the fields of data science, machine learning, cyber defence, modelling and simulation, and systems engineering.

STO-TR-IST-129 Predictive Analysis of Adversarial Cyber Behavior

This report summarizes the work and findings of the North Atlantic Treaty Organization (NATO) Research Task Group (RTG), Information Systems Technology (IST)-129, on Predictive Analysis of Adversarial Cyber Operations. The RTG found overall that there was little in the way of direct research on and solutions for predicting a cyber-adversary who launches an attack against a known vulnerability with an unknown exploit. As such, the work of IST-129 contains a body of work that provides researchers and organizations with a point of departure for continuing research. Of all our many findings and recommendations, the most important is that prediction of adversarial operations in cyberspace is complex but can be decomposed. Prediction offers great potential in many areas of cyber defence. Predicting adversarial operations will be a multimethod approach. A common taxonomy both for and about the threat, along with machine-readable language, will help. Cyber defence itself needs to be protected. Modeling of closed network systems is needed and we need data sets that are representative of reality.

STO-TR-SAS-134 Improving Defence Investment Portfolio Decisions: Insights from the Literature and National Practice

Defence Investment Prioritization (DIP) decisions are among the most difficult any nation makes. Challenges include complex military system interdependency, the significant cost of equipping military forces, distinct interests and cultures of military, political and commercial stakeholders and, most of all, uncertain future defence needs. This study offers valuable guidance to help build defence capital investment portfolios that realize desired long term national and alliance outcomes, combining insights from the relevant literature (operational research, systems analysis, decision analysis, etc.) with the results of a survey of national DIP practices. Responses from thirteen nations reveal a desire for more and better analysis and, in particular, a wide diversity in most aspects of national practice. This suggests a need less for procedures than for principles to govern sound long-term defence investments. Six Decision Quality (DQ) perspectives are proposed to manage the organizational, technical, analytical and uncertainty-based complexities of DIP. This framework offers analysts and decision-makers guidance in setting DQ goals and help in evaluating progress in building cost-effective portfolio alternatives to consider in the search for the best possible DIP portfolio.

STO-TR-SAS-150 Advanced Analytics and Artificial Intelligence for Defence Enterprise Resource Planning

Organisations in the early stages of delivering data analytics and artificial intelligence (AI) must carefully select use cases that generate the most value quickly. This selection can be informed through rapid, yet systematic assessments of the use cases' feasibility, cost, and their potential impact. The NATO STO Specialist Team SAS-150 developed and tested a prioritization method to conduct such assessments. The method was applied to ten candidate use cases of an enterprise resource planning (ERP) nature identified by participating nations. A use case proposed by the USA focusing on Condition Based Maintenance-Plus (CBM+) processes was selected as the most promising for collaborative work. The panel examined the application of machine learning to US army vehicle sensor and ERP system data to predict equipment failures and ultimately inform maintenance processes. It was outside the scope of SAS-150 to deploy predictive models for operational use, but the team was able to develop machine learning models that provide valuable insights using real vehicle data, while describing how models could eventually be deployed. This work demonstrates how the prioritization method, if applied properly, can successfully help senior leaders within NATO organisations identify the most promising use cases to advanced their data and AI strategies.

STO-TR-SAS-151 Intermediate Force Capabilities (IFC) Concept Development and Experimentation to Counter Adversary Aggression

Readers of this final report can expect to find a comprehensive guide to understanding, designing, developing, onboarding, and deploying game-based learning systems. The team gathered their collective expertise and their own lessons learned gained during their study developing and testing various game-based learning systems for cyber security. This guide is targeted to experts who are focusing on game-based learning approaches for enhancing current defence and education training and education methods. Critical distinctions are provided in the report for understanding and differentiating games, serious games, gamification, simulations, and wargames. The most common development problems and lessons learned from cyber security serious game projects are compiled within this report. Chosen design and development methodologies are discussed in depth for providing a quick guide to best practices to serious game development. These discussions were supported by case studies based on the SAS-129 team's own prototype development experience. The report also contains key information for experts looking for information on understanding the transformational needs of an organisation wishing to integrate game-based learning systems into its larger educational framework. Finally, the report includes a taxonomy of Cyber Security related game-based approaches that SAS-129 either developed or examined during its study. The taxonomy provides an overview of the full spectrum of game-based learning methodologies applicable to cyber security training.

STO-TM-SAS-MSG-ET-EZ Proof-of-Concept for Integrated Simulation and Wargaming Approach to Representing Intermediate Force Capabilities

Bi-panel Systems Analysis Study (SAS) – NATO Modelling and Simulation Group (MSG) stood up an Exploratory Team (ET) designated SAS-MSG-ET-EZ tasked with developing a Technical Activity Proposal (TAP) for a study integrating wargaming and simulation to represent Intermediate Force Capabilities (IFC) effectiveness. To support the TAP development, the ET designed and executed a proof-of-concept game combining tactical/operational constructive simulation (Command PE) and a menu-based strategic wargame to demonstrate the feasibility of integrating wargaming and M&S to represent, assess and compare IFCs effectiveness. The proof-of-concept wargame led to a number of lessons and recommendations for the proposed research group.

STO-TR-SAS-129 Gamification of Cyber Defence and Resilience

Readers of this final report can expect to find a comprehensive guide to understanding, designing, developing, onboarding, and deploying game-based learning systems. The team gathered their collective expertise and their own lessons learned gained during their study developing and testing various game-based learning systems for cyber security. This guide is targeted to experts who are focusing on game-based learning approaches for enhancing current defence and education training and education methods. Critical distinctions are provided in the report for understanding and differentiating games, serious games, gamification, simulations, and wargames. The most common development problems and lessons learned from cyber security serious game projects are compiled within this report. Chosen design and development methodologies are discussed in depth for providing a quick guide to best practices to serious game development. These discussions were supported by case studies based on the SAS-129 team's own prototype development experience. The report also contains key information for experts looking for information on understanding the transformational needs of an organisation wishing to integrate game-based learning systems into its larger educational framework. Finally, the report includes a taxonomy of Cyber Security related game-based approaches that SAS-129 either developed or examined during its study. The taxonomy provides an overview of the full spectrum of game-based learning methodologies applicable to cyber security training.

STO-TM-SAS-135 Analysis of Interoperability Factors Involved in the Sharing of Biometric Data

Data oriented to the fight against terrorism and criminality should represent a common resource to be shared among all concerned parties. In reality, as shown in the aftermath of several terrorist attacks, the sharing of such kind of data, at international level, is difficult. In particular, biometric data is especially valuable given its role in identifying persons of interest. The MIL Forces of several NATO Nations have acquired a considerable experience in the use of biometrics and an amount of biometric data has been collected. Although it would be helpful if this data could be shared, national legislations pertaining data collected in a military operation, along with a technical fragmentation in terms of standardization, currently, make biometric data sharing a complex task.

STO-TR-AVT-293 Effect of Environmental Regulation on Energetic Systems and the Management of Critical Munitions Materials and Capability

The Group in AVT-RTG-293 examined present and planned regulations to assess their impact on energetic systems for example through the EU REACH programme. It had become clear that the availability of energetic materials and related components was being affected by changes in environmental legislation and those effects across NATO needed to be understood. Active research options and programmes were reviewed to determine if they provide options for compliance. The Group also attempted to identify critical materials and to define routes for providing equivalent capability. Different national approaches were discussed, and the strengths and weaknesses assessed. The Group recommends a technical watching brief to prepare for future issues through investment in research and in contributing to the discussion of future environmental impact.

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