Technical Evaluation Report
SAS-165 Symposium on Assessing the Implications of Emerging Technologies for Military Logistics

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ABSTRACT

This technical evaluation report summarizes the essence of the presentations given during the NATO symposium, "Assessing the Implications of Emerging Technologies for Military Logistics", held in July 2022. It augments the papers collected in the proceedings, addresses salient points of keynote speeches, and presents a summary of presentations and considerations expressed in the symposium. It identifies key insights and provides recommendations for further work. The symposium provided a rich overview of thinking, planning, development and implementation of emerging and disruptive technologies (EDT) in the NATO and national logistics supply chain world. While the identification of key technologies was of primary importance, equally important was the presentation of tools, methods, studies, analysis, and reviews of EDT in logistics supply chains, and to learn of the NATO and national initiatives to bring EDT to fruition in military logistics. These innovative technologies will enable improvements to the supply chain alleviating the burden on manpower, realizing cost savings, providing visibility and logistics situational awareness, ease the task of provision of water and power in theatre, improve the maintenance and repair capability, support the planning of operations and save on necessary stockpiling of all supply classes, and above all prepare for the integration of all military activities into a seamless multi-domain execution of a military mission.

1.0 INTRODUCTION

For over 70 years, NATO has stayed at the forefront of technology to ensure the defence of its Allies and the success of its operations. In order to maintain NATO's technological edge, NATO has to have an understanding of how profound the impact of Emerging and Disruptive Technologies (EDT) is on security and defence. NATO 2022 Strategic Concept [1] formulates this as follows: "Emerging and disruptive technologies bring both opportunities and risks. They are altering the character of conflict, acquiring greater strategic importance and becoming key arenas of global competition. Technological primacy increasingly influences success on the battlefield." Technologies such as artificial intelligence (AI), autonomous systems, advanced manufacturing, biotechnologies and quantum technologies are changing the world, and the way NATO operates. In 2019 NATO Defence Ministers approved an EDT roadmap to help structure NATO's work across key technology areas. The NATO Science and Technology Organization (STO) developed Science and Technology trends to provide the context to underpin the development of this roadmap. STO is the world's largest collaborative research forum in the field of defence and security. It conducts and promotes activities in scientific and technological research to augment NATO and Nations' capabilities, and supports decision making in throughout the Alliance. Within the STO, the System Analysis and Studies (SAS) Panel functions as the expert panel for analytical advice by undertaking studies and analyses and the exchange of Operational Analysis and Research (OR&A) methods and tools to explore how an developed capability, a new concept, a change in organization or an innovative technology can be used and employed effectively or efficiently in an operational context [2].

The SAS Panel proposed and the STO approved the conduct of a Research Symposium on "Assessing the Implications of Emerging Technologies for Military Logistics". This symposium was held on 6 and 7 July 2022 in Rome at the Centre for Higher Defence Studies, the Italian Defence Joint Institution providing the highest education level on management, strategic leadership and defence & security related issues within the Italian armed forces. The symposium brought together subject matter experts in logistics, logistics technologies and those undertaking OR&A on future logistics capabilities from NATO member and partner nations in order to discuss and assess the impact of EDT on logistics. The symposium highlighted work across NATO developing logistics capabilities which make use of emerging technologies. It is expected that this will contribute to the development of future logistic operations, national acquisition and educational/training programmes, understand emerging interoperability challenges, and identify opportunities for wider collaboration. The conduct of the symposium must be understood in the context of NATO's transformational initiatives and its focus on innovation in which Allied Command Transformation in Norfolk VA spearheads NATO's capability development, the Science and Technology Organization acts as the watchdog of S&T foresight, and the North Atlantic Council (NAC) directs its major committees on implementing innovation and augmenting NATO's technology readiness through NATO's Innovation Board and the Advisory Group on Emerging and Disruptive Technologies.

1.1 Emerging and Disruptive Technologies

In the coming years the adoption of innovative technologies will be necessary as the interconnectivity between people, machines and services increases manifold. Whilst the existence of computing networks, big-data processing, digital transactions and ubiquitous sensing already seem to have established themselves as the norm in the wealthiest parts of the world, the global-scale transformation promised by these innovations is, in reality, in its early stages. The rapid adoption and integration of cyber-physical technologies will transform economies by redefining and removing established boundaries between industrial sectors, government institutions and other infrastructure constructs. Furthermore, advances in blockchain, distributed ledgers and crypto-tokens promise a profound influence on the impact of human activity in 'cyber-space' [3].

Militarily, this change in the technological landscape will redefine human organized conflict in a fundamental manner, manifesting itself in new ways of warfare. The future landscape of science and technology will be characterized by integrated and integral intelligence, analytics and decision making capability; exploitation of real and virtual networks overlapping warfare domains in which sensors, processes, organizations, individuals and autonomous agents connect; decentralised and ubiquitous large scale sensing, storage, computation, decision making, research and development; and blending of human, physical and information domains creating new realities [4]. The combination of these four factors will create autonomous systems and agents capable of more sophisticated decision making and self-directed activity. Furthermore, the new adaptive C4ISR networks will create risks and vulnerabilities because of the deep operational dependencies in military operations as they rely on seamless and ubiquitous connectivity between actors. Moreover, the larger operational environment (including cyber and space) and the interconnectivity between the traditional domains (air, land, sea) requires integrated thinking, planning and operating in a widely dispersed, interconnected, domain-agnostic manner. And lastly, while increased digitalization and miniaturisation across C4ISR capabilities enabled intelligent, interconnect and distributed systems and thus opened up new opportunities, they also increase their vulnerability to lower-cost and cheap precision weaponry and therefore introduce risks.

1.2 Logistics Innovation

Logistics is of vital importance for any military operation. Without it, operations could not be carried out and sustained. Logistics are planning processes for implementing and controlling the efficiency and effectiveness of transportation and storage of goods from home base to foxhole. While the adoption of EDTs has been eagerly understood in the C4ISR domain and therefore has the attention of the senior commander, the introduction of innovation within the logistics domain has been lagging. In order to

ensure the domain-agnostic, ubiquitous, interconnected conduct of military operations, it is necessary that military logistics innovation supports seamless operation by integrating thinking, planning, execution, and **sustaining** the operation, and that attention must be given to identifying and mitigating strategic vulnerabilities and dependencies, including with respect to NATO's critical infrastructure, supply chains and health systems. New technologies will support the cross-organizational supply chain, and will create a dynamic logistic function that include operational efficiencies and strategic flexibility, where "you ask and we deliver" will not do the job: it needs collaborative services which are similarly characterized as in the C4ISR realm: intelligent, interconnected, distributed and digital (I2D2). The road towards future logistics thus requires that logistics concepts need to adopt to new technologies and to adapt to changing operational contexts, i.e. concepts are to be sensitized to a multi-domain, interoperable, networked and connected environment and stress self-reliance, self-repair and resilience. EDTs are upsetting the logistics process and this leads to a need for an extended definition of military logistics to oversee the whole supply chain on a wider geographical scale to include relevant commercial entities and technologies from acquisition, management, distribution, transportation to education and training [5]. For operational logistics to innovate the interdependence with operations needs to be enhanced by integrating services in a collaborative manner, as is done in the commercial world. Individually, and in combination, new technologies have the potential to transform how military logistics information systems and services are provided.

The symposium was construed to highlight the changes occurring in logistics planning, the impact of technologies on the capability development and operational use of logistics, and in particular the transformation of logistics services as a result of digitalization. Within the planning sessions, papers were included to predict and forecast – as a results of EDTs – the effects of new threats and opportunities in general and of new methods of conducting maintenance, transportation, and supply in particular. Savings in manpower, material and supplies could be realized by applying analytics, artificial intelligence, autonomy and digitalization technologies, but most important is building a resilience in designing the NATO supply chain to cope with threats and opportunities that EDTs will bring. In the technology sessions, papers were to discuss the use of EDTs in autonomous systems, in alternative solutions that eased the burden on the supply chain, and in remote training and support. Examples of those were unmanned systems for sea and land operations, additive manufacturing and in-theatre generation of water. The papers on digitalization were chosen as they discussed how integrated systems and services using increased connectivity and interdependence realized by digitization could benefit the supply chain from supplier to customer and identified a number of very promising technologies, of which metaverse and blockchain were given special attention in dedicated papers.

After introductory remarks from Programme Committee Chair Dr. Marcus Tynnhammer, the Italian Joint Logistics Education Centre Director, Brigadier General Claudio Totteri, delivered a welcome address in which he emphasized the importance and timeliness of the symposium's conduct in light of the changing security environment, the increasing complexity of logistics operations, the involvement of civilian companies, and – as the topic of this symposium – the introduction of new technologies that will test NATO's ability to remain relevant, flexible and agile: "As in every combat field, technology-advanced logistics are fundamental for the success of any defensive or offensive operation". Gen. Totteri noted further: "The implementation of advanced technologies in military logistics is a strategic requirement of absolute importance".

2.0 KEYNOTE – MG DARIUSZ RYCZKOWSKI

The keynote address by Major General Dariusz Ryczkowski, Deputy Director of NATO Joint Support and Enabling Command (JSEC) in Ulm, Germany, was delivered virtually. JSEC was established during NATO's last command restructuring in 2018 in order to contribute to the enablement of reinforcement of the theatre, and when needed during crisis and conflict, to coordinate the reinforcement and the subsequent sustainment. Its main focus is currently the preparation of a network of contacts of all relevant authorities,

civilian, governmental or non-governmental institutions of NATO and EU member states. MG Ryczkowski explained how the 2019 EDT Roadmap brought a change in thinking at this command on the challenges that big data and advanced analytics posed in the realm of his mission and logistics in general. In line with how the thinking of STO and NATO HQ was developing, JSEC also realized that EDTs bring opportunities and risks and required a formal approach for a way ahead to prepare for a multi-domain operation in which logistics is fully integrated. Additionally, he explained that JSEC also has a role in the provision of relevant information on logistics for NATO in support of SACEUR's strategic level decision making. Establishment of a theatre-wide logistics operational picture will contribute to the overall situational awareness and the common operational picture. Integration of domain and functional area operational pictures will eventually lead to full situational awareness and possibly situational understanding in every domain. Initially, MG Ryczkowski reasoned, this should provide for a deep knowledge of infrastructure and assets for movement, transportation and sustainment. The current NATO logistics information system Logistics Functional Area System (LOGFAS) will be replaced to include new technologies such as artificial intelligence and analytics, but will also need to overcome the reluctance of nations in sharing information. For the latter, a legal framework will need to be built. In closing, the general requested the support from the STO community for the JSEC mission, and asked for national collaboration on technical matters with the NATO Communication and Information Agency (NCIA). He emphasized the work that needed to be done in policy and doctrine development to support the JSEC mission.

3.0 STREAM 1 – PLANNING (1)

The first session originally consisted of the presentation of three papers. Unfortunately, due to sickness, the presentation on "Earth Observation Supporting Defence and Intelligence Operations" was cancelled. This could have enabled an understanding on how satellite imagery exploitation based on emerging techniques and technologies can support Military Logistics transformation and evolution. The two other presentation emphasized studies and analysis on the effectiveness and feasibility of implementing new technologies to save resources, manpower and time.

3.1 A Novel Predictive Maintenance Methodology for Improving Defence and Security Logistics Processes

Mr. Luigi Ciolli presented the work of his team at Leonardo, Italy, on new methodologies to improve the Italian Air Force aircraft in-service operational availability and mission reliability. New maintenance strategies which rely on predicting and anticipating the likelihood of asset failures based on Emerging Machine Learning (ML) solutions allow for optimizing maintenance schedules and, consequently, the overall system life cycle cost. He discussed three separate Use Cases for which ML provided improved anomaly diagnosis in repair and maintenance activities, real-time aircraft availability by predicting likelihood of failure and remaining flight time, and engine testing optimization by simulation of a digital twin.

In the first Use Case Natural Language Processing (NLP) is used to provide maintainers who are attempting to solve newly raised anomalies, a comparison of them with past anomalies based on similarity – using a semantic text similarity approach – and suggesting solutions that correlate with the anomaly at hand. The second Use Case estimates an aircraft's remaining flight time by comparing the aircraft's key performance indicators with historical data stored into the legacy repository to calculate the improved potential aircraft availability. The Robust Statistical Sensory Data (RSSD) neural network uses data fusion to find the similarity trend between predicted data and historical data to forecast availability and then enable optimization of the maintenance schedule. The third Use Case presented how the number of Engine Test Stands (ETS), which in itself are extremely time-consuming and costly, can be reduced by subjecting the specific engine to a deep learning approach in a simulation environment. A digital twin of the engine is simulated, a comparison is made between different asset configurations for which an operator has chosen the engine parameters depending on the maintenance impact, and a decision is made what a

proposed solution should be. Mr. Ciolli argued that these Use Cases show the potential of the application of ML methods on both statistical and sensorial data, and point to future steps in which additional scenarios and extension of use cases serve as a demonstration of the benefits in military logistics.

These types of innovative methodologies show great promises for the reduction in maintenance and repair in terms of cost and time. For operators this approach allows for estimating the real residual operating hours of the assets, leading to a significant reduction of unplanned downtime, by managing their reliability risks and anomalies ahead of time. Application of machine learning technologies and the collection and sharing of data show the potential of what artificial intelligence, analytics and digitalization as emerging technologies may bring to the NATO logistics processes.

3.2 Feasibility Study Military Truck Platooning

Dr. Kerry Malone of the Netherlands TNO research institute briefed on a National Technology Project on the feasibility of introducing semi-autonomous driving into military logistics supply and distribution to logistics bases in theatre.

The need for the study arose from the Netherlands MOD perceived (future) shortage of drivers in parts of the logistics supply chain. In the civil domain innovations in the area of truck platooning are underway and progressing well and the first experiments on the road have already taken place. In truck platooning, trucks in a convoy are electronically linked together. The first truck is the leader, determining the speed and the route, while the other trucks in the convoy automatically follow, maintaining a configurable following distance. The success of civil domain experiments make truck platooning look promising for military applications. The study investigated whether truck platooning is technically feasible in the military context, and if so, whether further research may be necessary to understand the human factors and effects on logistics. The military environment is different from the civil one, where the latter can rely on traffic lanes, predictable traffic situations, and little disruption on the road. Military transport needs to occur in highly unstructured traffic situations and has to cope with possible interference in the delivery of goods.

Dr. Malone concluded that the study showed that truck platooning for defence appears technically feasible. This study identified what extra requirements the military application needs. In the short term, truck platooning with one driver per follower truck is envisioned. In the medium and long term, truck platooning will make use of higher levels of autonomy with driverless follower trucks. The first truck in the platoon retains a driver and co-driver to assure that the main decisions are taken by a human in the loop. This latter configuration requires significantly more study and investment to realize, compared to the former, where the driver can perform more complex manoeuvres, if required.

While truck platooning itself requires the introduction of new technologies to make semi-autonomous and autonomous driving possible, this study highlights the fact that new technologies are to be adapted to the operational environment and need to be embedded into policies, procedures and tactics to make actual innovation possible. In addition they are to be accepted by the rank and file within the military to be successful.

4.0 STREAM 2 – TECHNOLOGIES (1)

The first stream on technologies brought three presentations on the introduction of new military equipment that use emerging technologies to enable or support the operations in theatre. Two presentations discussed unmanned systems. Unmanned systems have been around for some time, but artificial intelligence, analytics, network-enabled synchronized operations, sensory data fusion and sharing have enabled the use of these systems within an operational environment. Logistical application of unmanned systems, while lagging the C4ISR usage, is currently explored, evident from the presentations in this stream. The third presentation showed how water generation as an emerging technology could be easing the burden currently placed on the

logistic supply chain.

4.1 Cost-Benefit Analysis for Unmanned Anti-Submarine Warfare Barrier Logistics

Dr. Robert Been, from the NATO's Centre Maritime Research and Experimentation (CMRE), La Spezia, presented a study on size and composition of the maritime task force necessary to conduct Anti-Submarine Warfare (ASW) barrier operations at maritime chokepoints in SACEUR's Area of Responsibility (AOR).

ASW barriers play an important role in limiting the strategic and tactical capabilities of an adversary. With the advancement of marine technologies to the realization of the widespread adoption of Marine Unmanned Systems (MUS) bringing increasing capacity and roles to MUS, an ASW barrier composed of MUS could reinforce or even replace classical deployments. However, a large number of MUS have to be deployed to achieve a comparable performance to a barrier with classical assets due to the limited capabilities of an individual MUS. For the maximum performance of such an unmanned barrier, methodologies are sought for optimizing the MUS fleet logistics and deployment.

The CMRE conducted a study and design of an optimization framework extending the analytical formulation of a single asset barrier patrol to many assets of heterogeneous manned and unmanned vessel types. Dr. Been explained that this was possible as a mathematical formulation, presented in linear algebraic format as an integer linear programming problem, albeit for a highly stylized and rigid scenario. He presented some solutions for different barrier lengths, task force compositions, and available logistics support options. The latter was of high interest to the symposium, as the results showed the task force's effectiveness and reach to be highly dependent on available logistics assets for launch and recovery of MUS.

This paper posed an interesting viewpoint, not only because of the elegance of the mathematical formulation producing quick results (as compared to a solution to be generated by brute force calculations in simulations), but also because it highlighted the issue of dependency on maritime support vessels, an issue that may easily be overlooked when logistics considerations are ignored or not taken into account as this happens frequently when operational planning is conducted in haste.

4.2 Atmospheric Generation: The Technological Solution to the Lack of Drinking Water in the Military Sector

Mr. Carlos Carcia, CEO of GENAQ Technologies, Spain, presented a technological solution to the lack of drinking water in military operations. As NATO and US operations in Afghanistan and Iraq have demonstrated, expeditionary missions have largely depended on bottled water resupply and non-potable local water treatment that include purification systems, chemical tabs, or advanced filters. Atmospheric water generators (AWGs) can produce water from humidity in the air, being the best choice in locations with unreliable or inexistent access to drinking water. These could include NATO missions of humanitarian character such as disaster relief and evacuation, as well as peace keeping and other missions in austere or infrastructure-poor environments.

Atmospheric water generation technology is based on cooling down the air below the dew point producing humidity to condense together with water treatment to ensure its quality. It has been available since the 1950s and combines several techniques including refrigeration by mechanical compression of a refrigerant gas, air and water filtration, ultraviolet disinfection, and mineralization.

Mr. Garcia explained that GENAQ has been developing this technology since 2008 based on proprietary design and advanced thermodynamic systems. As a results of this, the main limitations of this solution have been solved, namely reliability, water generation uncertainty, energy consumption, and drinking-water quality. This has been validated in real field operation in 59 countries with several armies and multilateral organizations.

This presentation highlighted the relevance of the application of various known technologies to progress to an innovative solution which is transportable, portable and adoptable to many military scenarios. Taking into account the logistics burden that has been placed on the provision of potable water, the adoption of this solution in a real environment can positively impact the water supply cost, casualties related to resupply, waste production, logistics, supply security, water quality, and water taste.

4.3 MULE – Military Unmanned Logistics Enabler

Mr. Andrea Maccapani, Unmanned System Engineering Architect at Leonardo provided the presentation on the potential of a Military Unmanned Logistics Enabler (MULE) within a possible future NATO scenario. Leonardo has many unmanned systems within its portfolio, however, mainly for surveillance, reconnaissance and payload delivery. Innovative solutions for logistics purposes in the civil world are being proposed and tests have been planned for long range heavy lift services. The challenge for a military combat logistics application is the provision of a resilient supply chain that can cope with threats and risks of a multi-domain combined arms scenario in urban and austere environments where insurgent opponents are limiting movement of the intervention force. An autonomous system with the ability to safely and speedily transport a considerable amount of resupply is seen as a viable, scalable and flexible force multiplier solution and an increasingly vital component for such military operational situations complementing current supply chains and enabling the provision of new logistic capability.

Mr. Maccapani's presentation highlighted the spin-off from civilian developments in logistic transportation of heavy loads, to benefit military purposes. Moreover, the civilian world explores emerging technologies and feed the consideration of military applications, reversing the trend of military innovation inspiring civilian developments. The presentation also emphasized the importance of an unhampered and resilient logistic supply chain to enable a military operation providing the desired effects of the (NATO) commander's mission.

5.0 STREAM 3 – DIGITALIZATION (1)

This stream contained two presentations on EDTs which are projected to have the biggest impact on the development and implementation of future logistics applications. In particular, the use of systems that incorporate new technologies for information sharing and cooperation between IT environments are understood as most promising.

5.1 Benefits of the Application of EDT in the Logistics Business Processes

Mr. Emilio Biasin, FalconOps Italy, gave a presentation on the benefits of the application of EDTs in the logistics business processes. He argued that a key component for NATO's capability development is the ability to address interoperability and standardization as the achievement of mission objectives depends on the close cooperation between employed military assets. In particular, interoperability between logistics information systems becomes essential for a commander's ability to create logistics situational awareness and understanding. The presentation focused on analysis of benefits through the application Artificial Intelligence (AI), Big Data Analytics and Blockchain technologies under a Cloud computing architecture, in improving the interoperability between National Logistics Information Systems to be capable of capturing, handling, processing, presenting and sharing high quality logistics information in a federated clouds context. Network enabled capability enhancing logistics information usage, logistic decision support with a recognized theatre logistic picture delivering situational awareness, and an information infrastructure providing an integrated coherent IT backbone, are requisites for a successful logistics operation. Within this, data is a strategic asset, and technologies such as Analytics and AI improve the generation of situational awareness collecting data from different heterogeneous sources. Adding blockchain technologies to this mix enables the prediction of maintenance, repair and supply needs.

This paper emphasized the importance of common NATO or coalition logistics business processes providing visibility and awareness of the logistics situation in an operation. Key is striving towards interoperability and integration of new weapon and support systems while the information on their logistics is being shared within a so-called federated mission network in a timely and secure manner.

5.2 Technological Aspects of the Capability Development of the Logistics Support

Col Pavel Foltin from the Department of Logistics at the Czech University of Defence, Brno, briefed on the technological aspects of logistic capability development. He argued that technological changes impact on the character, course and conduct of armed conflict. Asymmetric conflicts became possible because of an uneven balance in technology between nations, the emergence of information technologies and innovative thinking of the warring parties. The development of capabilities for the armed forces must kept abreast of and take into account Emerging and Disruptive Technologies (EDT) in order to prepare for a broader spectrum of warfare, counter threats and mitigate security risks.

Col Foltin further discussed the possibilities and opportunities of new emerging technologies for the development of military logistics capabilities over the short and long term. An Alliance eases the burden of keeping abreast of military technologies and assuring a technological advantage, to include the ability to respond to new technological opportunities, risks and threats.

Turning to the topic of logistics, Col Foltin pointed out that when the disruption of integrity and functionality of logistics chains is considered, this could be seen as a threat of strategic importance. It is therefore evident that it is necessary to identify the impact that significant EDTs have on military logistics capabilities. The paper reports by means of a content analysis of scientific publications on emerging technologies. Of key importance are AI, quantum computing, cloud technology, 5G networks, Big Data, Internet of Things (IoT), autonomous systems, robotics, digital twining, exoskeleton and 3D printing; and in addition, the combination of them resulting in synergy effects.

6.0 STREAM 4 – DIGITALIZATION (2)

The next stream on Digitalization discussed three important emerging technologies for the logistics information systems: metaverse, blockchain and the digital supply chain network. Metaverse is an emerging concept being the interface between the physical and virtual world. Blockchains are best known in the world of cryptocurrency, but its main characteristic in civilian application is the trusted ledger for exchanging value in a network of peers. A digital supply chain network would enable the safe, secured and trusted collection, storage and sharing of logistics information between nations.

6.1 Metaverse and Military Logistics

Capt. Ville Nokipii and Lt. Eemeli Kärkäs, Finish Armed Forces, presented their view on the impact of Metaverse on Military Logistics. Metaverse refers to the integrated digital platforms focused on virtual and augmented reality and the use of blockchain. Big-Tech companies have started to develop Metaverse eco-systems, standards and applications. This development may have various influences to the military logistics in the future. The presentation detailed on the study that mapped out the potential Metaverse applications for military logistics. Their method of a literature review and content analysis, qualitative in nature, revealed a challenge of finding other than mainly subjective sources referring to Metaverse. The concept of Metaverse is defined in various ways and consistency is still lacking.

The authors concluded that probably the most potential applications for military logistics are simulation and optimization of material flows, virtual modelling of the optimal deployment of troops, digital twins' management in maintenance operations, block chain technology in data flow, planning internal logistics of

new warehouses, training and operating autonomic systems in virtual reality.

Though Metaverse technology is years away from being fully realized, it is expected to eventually be a place where you can work, play, learn, create, shop, and interact with friends in a virtual, online environment. These conclusions suggest there to be several applications which can be of use in military logistics. It is apparent that the actual phenomenon of Metaverse itself needs more research and there is room for wider discussion of how it could be used in the field of military logistics.

6.2 Blockchain: Transformation of NATO Logistics Capabilities

CDR Burcu Rumelioglu, Turkish Navy and currently on the staff of HQ Supreme Allied Command Transformation (SACT), Norfolk, USA, provided the presentation on what Blockchain technology would mean for the Transformation of NATO's logistics capabilities. She started out by mentioning that smart contracts, smart cities, and cryptocurrencies are currently the most renowned applications of blockchain technology. As such those applications break so much with traditional practices and show the emerging and disruptive character of blockchain technology, that some describe these new applications being the result of the 'blockchain revolution'. A significant number of research projects have been conducted in this area and begs the question on how to adopt blockchain technology in the military domain.

Her paper focuses on a common understanding what blockchain technology encompasses, the potential opportunities for application in the logistics domain, and discusses a necessary NATO transformation in policies, procedures, doctrine and systems to adopt blockchain technology. She proposed a blockchain definition in a military context as "a distributed digital military ledger used between nations of alliances to exchange defence logistics value", such as a recognized logistics picture, asset tracking information, cross border documents. In a decentralized system, the responsibility does not belong to an individual, entity, or government because the blockchain technology takes the 'trust' element from the hands of a central structures and gives it to a decentralized structure, where the network itself develops the trust. As data is time-stamped and stored permanently on its digital ledger, unauthorized modification of permanent data is not possible, which is the main characteristic of the blockchain's immutable and irreversible record infrastructure, i.e. data is authentic. There are private and public blockchain networks. Private blockchain networks are "permissioned" allowing users to have certain (but not all) rights to reach the data and proceed the process.

CDR Rumelioglu pointed out that logistics in defence environment requires coordinated, collaborated and synchronized joint and multi-domain military and non-military, international and intergovernmental actions. Subsequently, interoperability to share data between platforms and to move it both horizontally and vertically in all levels becomes highly critical to support future's warfighter. NATO logistics relies on advanced, interoperable and trustable software systems populated by all players with all available, necessary and required data in order to conduct logistics services in a timely, secure and efficient manner. It is critical that the data is shared amongst all players and a broad agreement on sharing and exchange of data is necessary for the effective execution of NATO logistics. By developing a single and distributed ledger across NATO, data can flow among the users of the blockchain network. The users can be both military and non-military actors across public and private domains. As blockchain technology would take care of the data authenticity as the decentralized and trusted ledger in the NATO logistics chain, there will be a lesser burden on national entities to verify data, and would thus support NATO's transformation to a secure data centric and digital organization.

It is the intention of SACT to embark on a conceptual approach followed by experimentation in order to get a better understanding of the blockchain technology application. Initially, a survey conducted under NATO military staff identified a number of obstacles, leading to a conclusion that a development of a "*humble decentralized and trustable ledger*" for now, may be a preliminary working solution for working together in

a sustainable logistics ecosystem.

6.3 Real-Time Digital Supply Chain Network, an Emerging Technology

Mr. Michael Bruens, Director of Government Business Development and Programs for One Network Enterprises™ (ONE), Dallas, USA, provided the presentation on Real-Time Digital Supply Chain Network, consisting of several products developed by ONE.

Mr. Bruens explained how the success of joint military logistics operations can be significantly improved through a multi-party digital supply chain network that provides a single interface to all mission partners and addresses issues commonly encountered in any joint operation. Without a "Single Version of the Truth," (SVOT) which can only be established by collecting and managing data that is willingly shared by sovereign nations, logistics decisions often result in lack of visibility of levels, location, condition and status of materials and supplies.

Mr. Bruen argued that today's forward tactical operations lack visibility and key logistics support tools, requiring additional staff and supplies for any mission. A proper solution is highly secure, based on commercial capabilities, never goes legacy, and is supply and transportation agnostic. Using the concept of Multi-tier Control Towers enabling real-time visibility and mission planning, with execution, on the same system in addition to prescriptive analytics, artificial intelligence (AI), and machine learning (ML) capabilities adding logistics functions that can be automatically executed, it is possible to ensure items are where you need them when you need them.

This solution fulfils currently the operational requirements for any of the United States Department of Defense (US DoD) operations. It may be of interest to other nations allowing an interoperability between participating nations of the ONE network solution.

7.0 STREAM 5 – TECHNOLOGIES (2)

The second stream on technologies extended the first session with presentations on autonomy, additive manufacturing and opportunities that technologies bring to remote training in logistics. Robotics are starting to include cooperative strategies and dynamic exchange of data and information to optimize their employment. The ability to manufacture spare parts on location is better understood, but standardization would be helpful. Modelling and Simulation as a Service (MSaaS) and Virtual and Augmented Reality as technologies to conduct training, could be augmented by systems that provide documentation and expert reach-back through a cloud based system.

7.1 Logistics Application of Military Land Robotic

Col Pavil Foltin from the Department of Logistics at the Czech University of Defence, Brno presented the study on logistics application of military land robotic. He explained that for more than two decades technological developments in the domain of unmanned ground vehicles (UGV) have evolved steadily to the extent that contemporary technological advances within this area will allow the development of ground military robotics to reach the operational maturity stage. He expects that the introduction of that level of automation will have a transformational effect on the conduct of future military operations and in particular affect the logistics domain. Very low sensor and processing latencies will dramatically improve mission performance of robotic systems. This will lead to a trend to replace military personnel by robotics specifically in routine and dangerous tasks. It will grow the understanding that humans will be no match for robotics in the execution of these tasks. It will therefore fundamentally change our vision of the future military operational environment on the battlefield.

Specifically focusing in on the study, Col Foltin briefed the symposium on the modelling effort of the

process of operational logistics adaptive planning, where a UGV swarm is used to establish a supply delivery chain in the complex operational environment. One of the decisive components of the capability of future military robots is its operational decision-making capability. The study reports on the ability to measure the performance of the UGV swarm in future operations. Using optimization algorithms to solve this "travelling sales man" problem by minimizing costs for the delivery of ammunition to a number of outposts – a number that is limited by the area that sensors of a UGV swarm can survey dynamically – creating a so-called tactical manoeuvrability graph of nodes, solutions are produced for a swarm of 3 UGVs to demonstrate feasibility.

Col Foltin pointed out that further research and study is needed and that it has to be evaluated in practice and incrementally adjusted depending on the level of complexity meeting the operational needs and situational reality. It is believed that the problem itself has not been recognized and that a wider recognition of operational problems would initiate a broader interest in the "solution infrastructure" and cohesion of the operational and research/technical community.

7.2 Additive Manufacturing in the Army of the Czech Republic

Dr. Robert Kutil from the Department of Logistics, Czech University of Defence, Brno, presented his research on additive manufacturing in the Czech Army. The possibilities of 3D printing metal parts to support selected processes of military logistics in a multi-national operation were investigated using the tools of system analysis and brainstorming. An analysis of a selection of appropriate metal components and spare parts that are in demand within the Joint Operation Area, and which could be realistic and efficient to print, led to the concept of a Mobile Modular Container Workplace (MMCW) where selected certified metal components and spare parts could be manufactured, benefitting not only Czech Army, but also other NATO armies.

Dr. Kutil explained the challenges facing an implementation of the proposed additive manufacturing. First is the question of which 3D printing technology would be suitable for military application. Other issues considered were: which products would be suitable; how product reliability was to be measured and how certification would be reached; the need for development of NATO and EU Standardization, Standard Operating Procedures, and strategic deployment and support for the MMCW.

The paper highlights the benefits of additive manufacturing, even when one considers how to circumvent industrial licenses. While it may be less costly to ship spare parts from home base, the advantage of 3D printing can be a much faster commissioning of damaged military equipment in the event of a significant shortage of spare parts, namely on an international scale, and a faster return to combat capability. 3D printing can seem like an expensive but quick alternative to the lack of spare parts for maintenance and repairs and to the need to store a large number of these spare parts for a long time, with the risk that optimal use or consumption may not occur at all.

7.3 Digitalization, Cloud, Extended Reality and Connectivity for Remote Training and Support

Dr. Mathieu Terner from the Aircraft Division at Leonardo, presented the company's view on digitalization, cloud, extended reality and connectivity for remote training and support. He explained that in the demanding field of Aerospace, Defence & Security, operative and maintenance personnel must demonstrate excellence in guaranteeing operation of systems. Training and remote support are therefore critical activities strongly contributing to achieving this goal. Traditionally, satisfying highly standardized procedures and complex tasks presents significant drawbacks in terms of logistics, costs, safety & security and environmental considerations. Emerging technologies, particularly those promoting full interconnectivity, are promising innovative solutions to resolve these issues. Solutions such as Modelling & Simulation as a Service (MSaaS) and virtual, augmented and mixed reality (VR/AR/MR) provide

revolutionary approaches, able to drastically reduce costs and improve performances. Leonardo is developing alternative innovative solutions for remote training and support through the development of an integrated Collaborative Digital Platform allowing customers to be fully assisted in operation, connecting remotely with experts and accessing all relevant documentation stored and referenced securely on a cloud. Nevertheless, the success for implementation and operation of such dedicated platform is predicated on considerations including full connectivity, data ingestion and processing, cloud computing and cybersecurity, artificial intelligence to name a few.

Dr. Terner introduced the symposium audience to some Leonardo products: a cloud platform for MSaaS, a synthetic environment for simulations, a permanent network, a series of extended reality products for training and a platform for remote support featuring e-learning and collaboration. These services could be used in conjunction, in which the MSaaS could be a gateway for nations' own simulations as it manages hardware, software, simulators etc. to create any complex scenario for training. Additionally, the synthetic environment is able to simulate terrain, weather, synthetic forces etc. and provide an array of engagements from one-to-one air-to-air engagements, to complex missions, and from low to high intensity combat scenarios. A permanent network between M&S centers allows seamless interoperability across various M&S systems. Finally, within the high definition environment, the virtual maintenance trainer and the extended reality system allow training of maintenance, repair and troubleshooting within the simulation models. A collaborative digital platform complements the suite allowing to connect remotely operators and technicians to experts.

The application of these services could benefit many NATO's national military as they could pick the services that they require and build their own simulation environment supported or not by Leonardo's products.

8.0 STREAM 6 – PLANNING (2)

The last stream was devoted to planning. The three presentations focused on current thinking and understanding of the opportunities and risks that EDT bring to the logistics supply chain, on the effects on NATO's defence planning outcomes as EDT are being introduced in new operational concepts, and how forecasting a particular class of supply (ammunition) using M&S tools would alter the planning of stockpiles.

8.1 Disruptive Technologies and Defence Supply Chain Design

Dr. Marcus Tynnhammer and Mr. Göran Kindvall jointly presented the Swedish Defence Research Institute (FOI) study on disruptive technologies and defence supply chain design. Supply chain risk management is appropriate to deal with known uncertainties, where we know probabilities and impacts of occurrence. However, supply chain risk management is not sufficient to deal with the unexpected. To make defence supply chains resilient against Black Swan events, or the unknown unknowns, including disruptive technologies, another approach is required.

They explained that the purpose of their paper is to serve as a first step towards establishing such an approach. It identifies and categorises different types of potentially disruptive technologies, which are likely to have a significant impact on defence supply chains. This is done through a literature reviews, workshops conducted with officers of the Swedish armed forces and field trials in Swedish military exercises. The paper also initiates a discussion regarding possible threats and opportunities associated with such technologies. Questions such as how will digitalisation, additive manufacturing, artificial intelligence, and autonomous systems affect future defence supply chains; how will the transformation to fossil-free societies affect different nations' fuel-solutions; how will potentially different national fuel-solutions affect interoperability within NATO, and how will it affect host nation support?

The authors also identified the likelihood of an increasing amount of civilian technology in military systems, the necessary adaptation of military forces to measures for limiting climate change, and the realization that technology is also becoming a strategic tool in the struggle between major powers. The technology areas of particular interest in logistics that have been studied and are of particular interest for discussions on technology-driven disruptions in defence supply chains are: data, artificial intelligence, autonomy, biotechnology, materials, energy and sensors.

The value of the paper lies in posing questions associated with designing defence supply chains that are resilient to disruptive technologies. The paper is a first step towards creating a deeper understanding of how military logisticians must incorporate the occurrence of Black Swan events, including disruptive technologies, in their design.

8.2 Exploiting NATO Defence Planning Process (NDPP) to Support the Test-Bedding of Emerging Logistics Technologies

Mr. Scott Joyce of the NATO Communications and Information Agency (NCIA), The Hague, briefed the audience on aspects of the NATO Defence Planning Process (NDDP) and how it could be used to support experimentation of concepts that include emerging logistics technologies in order to inform NATO's capability development and assess the effects on the NATO Defence Plans and NATO Targets apportioned to the nations. The tools and products of the NDPP can be used to support test-bedding analysis of emerging technologies. After explaining the five steps of the NDPP, Mr. Joyce indicated that test-bedding is most applicable informing capability roadmaps of the benefits of new technologies to deliver an effect. Using scenarios and tools normally used in the derivation of requirements, test-bedding a new concept or technology allows the assessment of potential impact to support the development of future and long term aspects.

Examples of test-bedding in logistics is the work on Joint Sea Based Operations, a concept in which logistics does not have a land-based footprint, and on Additive Manufacturing in which questions were posed on what supply classes would be candidates, how those stocks could be manufactured and in which framework such a capability had to reside. For both, analysing the effects on reducing logistics footprint, costs, efficiency etc. provides a measure of effectiveness to compare with existing practices. Mr. Joyce concluded that the test-bedding could be applied to other areas such as Unmanned and Autonomous Systems, and Alternative Fuels or Power.

The presentation highlights the need for analysis and assessment of the effects of new technology implementation, i.e. the innovative use of EDT in the sense that it is the combination of technology and application that leads to a change in procedures, a reduction of costs, an improvement in combat operations, or an increase in interoperability and situational awareness. Using tools from the NDPP ensures that the measure of effects is immediately comparable to the planned NATO force structure that was agreed by the official NATO capability targets.

8.3 Using Modelling and Simulation to Forecast Munition Consumption

Col Francesco Cardone, Italian Army, assigned to the Multinational Logistics Coordination Centre (MLCC) in Prague, provided the presentation on using M&S to forecast munition consumption. Stockpiling ammunition, especially specialized ammunition such as smart weapons, is quite a burden on national defence budgets. Stockpiles must be large enough to ensure the readiness of forces for deployment in operations and the effectiveness of forces in combat but at the same time they should not be excessive to reduce unwanted costs in procurement and management activities. Additionally, it may be necessary to allocate and reserve industrial capacity in times of crises to shorten the lead times to set up production and procurement. Current stockpile calculations are largely based on World War II and Korean War data. Any improvement in forecasting ammunition stockpiles could potentially save costs.

The MLCC proposed to use a simulation-based methodology to estimate the consumption of ammunition in current (and future) operations and reliably support the calculation of the related inventories. Col Cardone elaborated on the steps of a study to pursue this objective, which included the definition of a reference scenario and a descending course of conducting combat operations, according to the current NATO/national doctrine; the execution of live exercises supported by tactical simulation systems, consistent with the reference scenario, in order to collect data on realistic use of ammunition; and the development of a calculation algorithm to determine an average daily consumption.

The paper describes the results of the first experimentation and the subsequent results emerging from the developed algorithm and finally outlines some possible lines of cooperation with the NATO nations to properly implement such algorithm in support of stockpile calculations.

It should be noted that the results are preliminary and that robustness of the results must be obtained by investigating the consumption rates in various scenarios that need to be validated against their applicability for and representation of future NATO operations, by application of a wide range of statistical tools to account for variability in results, and by assertion that small scale live exercises could be extrapolated to larger scale combined combat operations. In addition, it would be necessary to consider how well current NATO Stockpile Planning Guidance compares to the results obtained by the algorithms.

9.0 END-NOTE – PROF ALAN MCKINNON

The second keynote address was delivered at the end of day 2 of the symposium by Professor Alan McKinnon, Professor of Logistics, Kühne Logistics University (KLU). He began by remarking that there are similarities and at the same time differences in logistics and supply chain challenges, objectives and performance between commercial/civilian logistics and the military version. He reminded the audience that "the military side of logistics may have had a head start… However, the truth is that civilian logistics and supply chain management surpassed military logistics at some point after the Second World War." [6] According to business and consultancy media, the top tier and dominant logistics technology trends are blockchain, automation, autonomous vehicles, and internet of things (IoT), followed by artificial intelligence, robotics and drones. However, as he pointed out, over time the hype in expectations is frequently followed by a trough of disillusionment, and this may come for AI and blockchain, and is currently happening for analytics. Professor McKinnon elaborated on what the underlying drivers are for turning towards technology as a solution. Labour shortages, improvement of supply chain resilience, decarbonisation of logistics operations and growth of e-commerce are the key drivers. In combatting the first one, commerce is relying on automated warehouse solutions and transition to driverless road transport. Prioritising supply chain resilience is a response to global supply chain disruptions and rate hikes, which may be obtained by improving logistics visibility through blockchain, cloud computing and IoT technologies and the application of predictive analytics. Professor McKinnon spend a great deal of time to explain decarbonisation: there is a global trend in commerce to contribute to the decarbonisation of freight movement. Recycling and 3D printing reduce the need for transportation and a shift to inter-modal and synchro-modal transport may lower carbon emissions. Optimizing the utilisation of vehicle capacity through freight control and visibility, truck convoying, container space management and networking to allow asset sharing, are solutions using the top tier logistics technology trends. Lowering carbon content in fuels or using low carbon energy (electrification, hydrogen, etc.) require different types of technology than discussed earlier in order to become carbon neutral or negative. Lastly, by transforming "last-mile logistics" using robotics and autonomy, the growth of e-commerce may be sustained. Professor McKinnon closed by emphasizing how military logistics could benefit from the developments in the commercial and civilian side of the house: it is clear that commercial logistics will see quicker adoption of innovative technologies which can then spill-over to the military side.

Transferring into the military realm the challenges faced in commercial logistics, sketched by Professor

McKinnon in his keynote, we can see similarities and differences between the two. As in the civilian world, NATO militaries are facing personnel shortages, require visibility of material and supply flows through the logistics chain, and need solutions for "last-mile logistics", albeit for other reasons than optimization of delivery vehicles. Unmanned and autonomous vehicles, automation, artificial intelligence and robotics are technologies to "man" the supply chain and to support the warfighter when goods are finally delivered. Last-mile logistics in a military operation is different because of the presence of threats and risks from opponents and chaos and fog of war that is typical for the crises or war environments. Digitalization, analytics, cloud computing, big data, IoT and blockchain technologies are applied to enhance logistics visibility to support combat operations and command and control, not only to save costs but also saving lives. Decarbonisation of the military inventory – not only for transport but also for the provision of power to command posts, supply depots, combat units and the like – will reduce the logistics footprint and ease the burden on the supply chain for the provision of fuel. Local water and power generation using e.g. air humidity and solar energy respectively are obvious solutions in that respect.

10.0 SUMMARY AND RECOMMENDATIONS

The symposium served a number of aims and objectives. Most importantly, it demonstrated military relevance as logistics concepts, procedures and doctrine need to adapt to the changing operational context. The realization that future conflicts and crises require an integration of all military activities to ensure domain-agnostic, ubiquitous and interconnected conduct of military operations, feeds the notion that it is not only necessary that military innovation supports seamless operations by integrating thinking, planning and execution, but that it also integrates the sustainment of operations [5]. One of the aspects in the changing operational environment is the introduction of emerging and disruptive technologies (EDT) presenting both opportunities and risks. Within the context of NATO's 2022 Strategic Concept [1], the symposium addressed the need for understanding what new technologies mean for NATO: altering the character of conflict and influencing the success on the battlefield. The NATO STO established as a priority the identification of EDT in Defence and Security [4]. While a great deal of R&T effort has been expended in identifying, exploring, researching, developing and implementing innovative technologies in the processes of the conceptualizing, development and acquisition of military (weapons) equipment, C4ISR capabilities and combat operational needs, the STO has commissioned only a few activities that have been focused on the logistics supply chain itself.

One of the functions of the SAS Panel is to provide expert advice using analytical methods and tools to explore how a developed capability, a new concept, a change in organization or an innovative technology can be used and employed effectively or efficiently in an operational context. Combining the priority of understanding EDT and providing a necessary focus on logistics, this symposium served the purpose of exposing the NATO S&T to developments in innovative technologies that bear upon the logistics supply chains of NATO nations.

The symposium provided a rich overview of thinking, planning, development and implementation of emerging and disruptive technologies in the NATO and national logistics supply chain world. Two keynote addresses and sixteen presentations, supported by papers, explored the effects of EDT on military logistics. While the identification of key technologies was of primary importance, equally important was the presentation of tools, methods, studies, analysis, and reviews of EDT in logistics supply chains, and to learn of the NATO and national initiatives to bring EDT to fruition in military logistics. We learned of the primary EDT for logistics: blockchain, metaverse, predictive analysis, AI, unmanned and autonomous vehicles, robotics, IoT, additive manufacturing, digitalization, cloud computing, networked logistics IT systems for real-time management and for simulation, among others. These innovative technologies will enable improvements to the supply chain alleviating the burden on manpower, realizing cost savings, providing visibility and logistics situational awareness, ease the task of provision of water and power in theatre, improve the maintenance and repair capability, support the planning of operations and save on

necessary stockpiling of all supply classes, and above all prepare for the integration of all military activities into a seamless multi-domain execution of a military mission.

10.1 Recommendations

A number of recommendations can be made that would benefit not only the S&T community but also the operational military audience. In particular:

- In order to ensure the domain-agnostic, ubiquitous, interconnected conduct of military operations, it is necessary that military logistics innovation supports seamless operation by integrating thinking, planning, execution, and **sustaining** the operation, i.e. the commander's focus should cover all aspects of the operation. Conceptual thinking within the Strategic Commands, academic research at the national Defence Academies, and experimental practices at military operational levels in nations, may be undertaken to realize what is necessary to make such integration come to fruition.
- As military logistics will benefit from spin-off in development and implementation of new technologies in the civilian logistic sectors, a close eye should be given to the practices and innovations on the commercial side. In that respect Professor McKinnon's lecture provided a close look at what happens on the commercial side. A dialogue with the civilian logistics sectors should be started possibly through an initiative by NATO staff. As a minimum, a technology watch for logistics innovation and application covering both the commercial and the military realms should be initiated at the STO or within Allied Command Transformation (ACT).
- Nations and NATO are encouraged to continue their efforts with EDT developments in military logistics supply chains, and the STO may want to foster the sharing of ideas, information and collaborative activities in order to promote innovation in logistics. The SAS Panel could discuss further exploration of studies and analysis on logistics with emphasis on EDT where desired. If possible, inter-Panel activities within the collaborative S&T activities could also be pursued.
- Dissemination of material that supports a further and wider understanding of emerging technologies such as Metaverse and Blockchain specifically, and AI, analytics, cloud computing and digitalization in general is encouraged within the national militaries, the NATO HQ, Commands and Agencies, and in NATO's Centres of Excellence. This will support military capability development, particularly in logistics. Attention should be given to activities in ACT with respect to blockchain ("Humble Ledger" in 2023), and interoperability, logistics visibility and situational awareness (through "Enabling Support Services").
- NATO Defence Planning test-bedding may consider the implications and effects of a wider application of concepts of Truck Platooning, Unmanned ASW barriers, Unmanned Logistics Vehicles, Water Generation and Additive Manufacturing. This could be in cooperation with involved nations. Defence Planning may want to notice the MNCC work on forecasting ammunition and understand how this affects the NATO Stockpile Planning Guidance.
- NATO and national entities may want to explore the capabilities of services offered in presentations by private companies during the symposium. Methodologies for predicting maintenance and repair, networked services for visibility and situational awareness, and M&S as a Service (MSaaS) are just a few examples.
- Further literature review of promising EDT is encouraged. Initiatives briefed at the symposium may provide opportunities for collaborative work between nations, possibly within a STO context.

It is recommended that the symposium outcomes are shared widely within the NATO STO, the nations, throughout the NATO Commands (ACT and ACO) and within the NATO committees. Specifically, a presentation to the Military Committee, the S&T Board and the Logistics Committee would be beneficial exposing all to the importance of emerging and disruptive technologies for the realization of an effective

and efficient NATO supply chain management and execution. Sharing the report with entities such as the JSEC and the MNCC would be beneficial for their staff. Equally important is distribution to other S&T Panels and the M&S Group.

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