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Artificial Intelligence and Autonomy in the Military: An Overview of NATO Member States' Strategies and Deployment

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Abbreviations

AI	Artificial Intelligence
AMD	Air and Missile Defence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBRN	Chemical, Biological, Radiological, and Nuclear
CCDCOE	Cooperative Cyber Defence Centre of Excellence
CCW	Convention on Certain Conventional Weapons
DARPA	Defence Advanced Research Projects Agency
DL	Deep Learning
EDT	Emerging and Disruptive Technologies
FCAS	Future Combat Air System
GGE	Group of Governmental Experts
ICBM	Inter-Continental Ballistic Missile
IFF	Identification Friend-or-Foe
JAIC	Joint Artificial Intelligence Centre
LAWS	Lethal Autonomous Weapons Systems
ML	Machine Learning
MUAAR	Military Uses of Artificial Intelligence, Automation, and Robotics
NATO	North Atlantic Treaty Organisation
NATO STO	North Atlantic Treaty Organisation Science and Technology Organisation
NATO NCI	NATO Communications and Information
NSM/JSM	Naval Strike Missile/Joint Strike Missile
PfD	Partnership for Defence
RAS	Robotic Autonomous System
S&T	Science and Technology
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UK	United Kingdom
UN	United Nations
US	United States
UUV	Unmanned Underwater Vehicle

1. Executive Summary

This report examines how NATO member countries think about and use AI and autonomous systems in their militaries. It provides an overview of NATO countries' AI ambitions and looks at how NATO members' militaries are *actually* using AI.

→ *Early Days:* While military AI is certainly important and may have a revolutionary impact in the future, it is still in a very early stage of development. Many states do not have a public AI strategy, and the majority (aside from France and the United States) do not have a dedicated defence AI strategy. Where states *have* outlined their positions on military AI-enabled technology, doctrine tends to employ different terminology (for example, with different thresholds for true autonomy) and demonstrate different levels of willingness to deploy technologies.

→ *Fragmented Innovation:* There is a significant capability gap between NATO members dividing those who are investing heavily in AI-enabled and autonomous military technology from those who are not (see Appendix A for more details). While approaches and perspectives differ across the Alliance, there is a significant amount of intra-Alliance cooperation taking place, in which member states pool their resources to develop and secure AI-enabled and autonomous military.

→ *Developing Understanding:* NATO agencies have released a number of reports highlighting a deep understanding of how AI-enabled technology will impact warfare and NATO's armed forces.

→ *Security and Military AI Applications:* There are a range of security vulnerabilities to current AI technology that must be acknowledged when designing and deploying AI-enabled systems appropriately, especially in a military context.

→ *A NATO AI Strategy:* NATO adopted an AI strategy in October 2021, which established the intended standards and roadmap for AI capability building and responsible use across the Alliance. This policy is likely to prove useful as a starting point for discussion and consensus-building between Allies.[1]

1.1. Policy Implications

→ As a consensus-based Alliance, NATO has the opportunity to facilitate discussions and potential norm-building exercises between members.

→ Greater collaboration may enable member states to leverage capability building efforts and better face the challenges associated with security vulnerabilities and wider limitations to AI technology.

→ A widening capability gap in AI-enabled technologies may result in some member states being relatively less equipped to respond to a faster conflict environment in which adversaries rely on AI-enabled and/or increasingly autonomous systems.

→ NATO may be a mechanism through which capability-building guidance and wider assistance may be provided to members on demand.

→ Siloed innovation also raises future interoperability challenges for the Alliance, in terms of sharing data and AI applications in multinational operations.

1 Zoe Stanley-Lockman and Edward Hunter Christie, "An Artificial Intelligence Strategy for NATO." NATO Review, NATO Review, 25 October, 2021, Accessed 2 December, 2021, https://www.nato.int/docu/review/articles/2021/10/25/an-artificial-intelligence-strategy-for-nato/index.html.

2. Introduction

Across many spheres, artificial intelligence (AI) is expected to transform basic tasks and processes in ways that promise to fundamentally change the nature of work. In the defence domain, AI is an emerging technology that has been incorporated into a wide range of applications from autonomous vehicles to data processing and logistics tools.

This paper offers a high-level view of the role of AI-enabled and autonomous technologies in the militaries of NATO Allies as of January 2021. The following overview of doctrine and individual state policy does not attempt to provide exhaustive coverage of each state's programmes and AI-enhanced military capabilities but instead aims to offer a snapshot of the perspectives, outlook, and maturity each state holds in relation to military AI innovation.

While other papers have examined the role of AI in the military, many focus on ethics and theory, and none have focused specifically on NATO. Research on military AI in practice tends to examine the US, China, and Russia, largely ignoring smaller countries. However, this report aims to study military AI in all NATO countries.

Section III of this report lays out the context for why militaries may choose to integrate AI-enabled and autonomous technology into military systems and outlines the definitions of AI, drawing on established understandings of the term through peer-reviewed literature and as defined by NATO member states. Distinctions between definitions will be discussed, including the distinctions between the concepts of AI, autonomous systems, and autonomy more generally.

Section IV discusses a number of potential vulnerabilities and problems with AI-enabled and autonomous weapons systems.

Section V outlines NATO's public position on AI in the military and briefly outlines the feasible capabilities of NATO as a mechanism for cooperation and collaboration in terms of sharing AI-enabled tools and relevant data between allies.

Section VI broadly discusses the role of AI in NATO member countries' militaries, examining why countries have or have not published national or military AI strategies and how NATO countries work together to develop military AI.

Section VII categorises the kinds of AI-enabled and autonomous systems found in NATO countries' militaries. AI-enabled and autonomous systems found in NATO militaries can largely be placed into four main categories: Autonomous Vehicles; Autonomous Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft; Data Analytics; and Logistics and Personnel Management.

A separate document, Appendix A, outlines the specific approaches of each NATO member state on the issue of AI applied in a military context. For each country profile, the report explores whether the state has an AI strategy, and if so, how the strategy addresses questions of national and international security. The report will highlight known military implementation (or planned implementation) across Autonomous Vehicles (unmanned aerial, ground, underwater, and surface vehicles); Autonomous Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft; Data Analytics; and Logistics and Personnel Management.

The research for this report relies on open-source and publicly available data; many states will be keeping the exact nature of their investment in military AI applications secret, in line with national security objectives. Nonetheless, an analysis of government policy documents and doctrine, as well as reflections from established research institutes, delivers useful insight on the path each state is taking concerning AI in a military context.

3. Definitions and Context

In August 2020, in a virtual reality simulation, an artificial intelligence (AI)-controlled F-16 designed by DeepMind, an AI company owned by Google, beat a human F-16 pilot 5 to 0 in a dogfighting competition.[2] In recent years, AI-enabled technology has rapidly advanced and been applied to a number of industries. For example, AI algorithms solved the protein-folding problem in biology,[3] beat masters at notoriously difficult board games like chess[4] and Go,[5] and can diagnose some forms of cancer even more reliably than human doctors.[6]

Not only is AI being integrated in the civilian sector, but militaries around the world have also started to integrate and consider the use of advanced AI in military systems. A number of countries already use some basic AI and autonomous systems in their militaries and are in the process of developing more advanced AI capabilities. Several countries, like the United States and France, have released military AI strategies, outlining how AI will be used in their military systems. Others, like the United Kingdom, have established military AI research centres.[7]

NATO's Science and Technology Organisation (STO) defines AI relatively broadly, as 'the ability of machines to perform tasks that typically require human intelligence'.[8] The STO and the US's Defense Advanced Research Projects Agency (DARPA) categorise AI innovation in several waves,[9] including 'first-wave' or 'knowledge-based' AI and 'second-wave' or 'data-based' AI.[10]

→ 'First-wave' AI (sometimes called 'knowledge-based' or 'expert systems') has existed for decades and is already integrated into a number of systems, both military and commercial. Knowledge-based AI systems rely on rules-based decision-making, facilitating automation by using expert knowledge hand-crafted by humans and a number of if-then statements to dictate their actions.[11] Knowledge-based systems cannot reason about situations outside of their carefully crafted if-then knowledge, nor can they learn from their experiences, making them incredibly brittle.[12]

→ 'Second-wave' or 'data-based' AI systems solve specific problems by using statistical models that are trained on large, sometimes pre-labelled data sets.[13] Data-based AI includes machine learning (ML) and its sub-set deep learning (DL), which have seen considerable growth in recent years, in large part because of advances in deep learning neural networks. Machine learning algorithms include supervised, unsupervised, and reinforcement learning.[14] Data-based AI models are entirely reliant on the data they are trained on. For example, a drone equipped with second-wave AI data analytics and surveillance technology may be able to identify a mobile intercontinental ballistic missile (ICBM) base from a photo by using a statistics-based image recognition15 model trained on pre-labelled images of mobile ICBM bases.

Throughout this report the terms 'autonomous' and 'AI' will both be used. The authors acknowledge that to many familiar with the technical terminology, 'autonomy' and 'artificial intelligence' may be considered distinct terms. Agreement on what the terms 'autonomy' and 'AI' mean varies within academic literature, often in inconsistent ways. For instance, some no longer consider 'first-wave' systems,

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2 Will Knight, 'A Dogfight Renews Concerns About AI's Lethal Potential', *Wired*, Conde Nast, 25 August 2020. Accessed 14 November 2020. https://www.wired.com/story/dogfight-renews-concerns-ai-lethal-potential/.

3 Sigal Samuel, 'AI Has Cracked a Problem That Stumped Biologists for 50 Years. It's a Huge Deal', *Vox*, 3 December 2020. Accessed 14 November 2020. https://www.vox.com/future-perfect/22045713/ai-artificial-intelligence-deepmind-protein-folding.

4 Will Knight, 'Defeated Chess Champ Garry Kasparov Has Made Peace With AI', *Wired*, Conde Nast, 21 February 2020. Accessed 15 November 2020. https://www.wired.com/story/defeated-chess-champ-garry-kasparov-made-peace-ai/.

5 Cade Metz, 'Google's AI Wins Fifth and Final Game against Go Genius Lee Sedol', *Wired*, Conde Nast, 14 March 2016. Accessed 17 November 2020. https://www.wired.com/2016/03/googles-ai-wins-fifth-final-game-go-genius-lee-sedol/.

6 Scott Mayer McKinney et al., 'International Evaluation of an AI System for Breast Cancer Screening', *Nature* 577 (2020): 89–94. https://doi.org/10.1038/s41586-019-1799-6.

7 Dan Sabbagh, 'Hackers HQ and Space Command: How UK Defence Budget Could Be Spent', *The Guardian*, 18 November 2020. Accessed 10 December 2020. https://www.theguardian.com/uk-news/2020/nov/18/hackers-hq-and-space-command-how-uk-defence-budget-could-be-spent.

8 NATO Science and Technology Organization, 'Science and Technology Trends 2020–2040: Exploring the S&T Edge', March 2020. Accessed 5 November 2020. https://www.nato.int/nato_static_fl2014/assets/pdf/2020/4/pdf/190422-ST_Tech_Trends_Report_2020-2040.pdf.

9 DARPA, 'DARPA Perspective on AI', U.S. Department of Defense, 15 February 2017. Accessed 12 November 2020. https://www.darpa.mil/about-us/darpa-perspective-on-ai.

10 NATO Science and Technology Organization, 'Science and Technology Trends 2020–2040: Exploring the S&T Edge'.

11 K.P. Tripathi, 'A Review on Knowledge-based Expert System: Concept and Architecture', *International Journal of Computer Applications* (2011): 19–23; Carol A. Koperna, 'Practical Issues for Expert Systems', Lehigh University, 1 January 1986. Accessed 18 November 2020. https://preserve.lib.lehigh.edu/islandora/object/preserve:bp-13897820.

12 Koperna, 'Practical Issues for Expert Systems', 8; Daniel E. O'Leary, 'Expert Systems: History, Structure, Definitions, Characteristics, Life Cycle and Applications', Marshall School of Business, University of Southern California. Accessed 8 January 2021.

13 Michael Tamir, 'What Is Machine Learning?' [UC] Berkeley School of Information, 26 June 2020. Accessed 6 November 2020. https://ischoolonline.berkeley.edu/blog/what-is-machine-learning/.

14 For more information, see Tamir, 'What Is Machine Learning?'.

15 Lindsay Schardon, 'An Introduction to Image Recognition', Python Machine Learning, 31 October 2020. https://pythonmachinelearning.pro/image-recognition-guide/.

which do not use ML, to be AI. Scharre and Horowitz (2015) propose a basic definition of autonomy when writing about autonomous weapons. They write that 'autonomy is the ability of a machine to perform a task without human input', though they point out that this may or may not involve aspects of artificial-intelligence technology.[16]

Some also make a distinction between 'autonomous' systems and 'automated' or 'automatic' systems. For example, NATO's Allied Command Transformation differentiates between 'autonomous' systems and 'automated' systems in the following way:

→ autonomous functioning refers to the ability of a system, platform, or software to complete a task without human intervention, using behaviours resulting from the interaction of computer programming with the external environment. Tasks or functions executed by a platform, or distributed between a platform and other parts of the system, may be performed using a variety of behaviours, which may include reasoning and problem solving, adaptation to unexpected situations, self-direction, and learning. Which functions are autonomous – and the extent to which human operators can direct, control, or cancel functions – is determined by system design trade-offs, mission complexity, external operating environment conditions, and legal or policy constraints. This can be contrasted with automated functions, which (although they require no human intervention) operate using a fixed set of inputs, rules, and outputs, the behaviour of which is deterministic and largely predictable. Automatic functions do not permit the dynamic adaptation of inputs, rules, or outputs.[17]

Given the frequent conflation of the terms 'autonomy', 'autonomous systems', and 'AI' in documents reviewed for this report, the authors' terminology follows the tendency of a number of NATO members to define AI and autonomy as technologies capable of going *further* than automated behaviour. Within this report, the word 'autonomous' will generally be used to describe first-wave-like systems that physically operate on their own and respond to their external environments. The term 'AI' will be used to describe second-wave data analytics, control systems, and decision support systems. When describing *specific* military systems, the authors use the same terms used by the manufacturers or by third-party experts describing the system (for example, L3Harris describes its MAST-9 ASV as 'autonomous', so the authors describe the MAST-9 as 'autonomous'). Within this scope, autonomous systems do not necessarily represent or contain AI-enabled or ML capabilities.

AI and autonomous systems are attractive technologies to militaries for a number of reasons. First and foremost, AI has shown the capability to outperform humans in automated military and civilian tasks, and increasingly in more demanding tasks,[18] though these capabilities are still relatively untested. As was previously noted, AI systems have outperformed humans in tasks including dogfighting, board games, and cancer detection. AI has the potential capability to facilitate more precise weaponry, more accurate data analysis, and earlier warning of attacks.

Second, AI processes information much faster than humans. The speed of these systems is likely to prove crucial as AI-enabled technologies are embedded across military decision-making processes, including nuclear decision-making,[19] in which military officials may have only a few minutes to decide how to respond to a nuclear threat. Moreover, AI will be essential to control systems that move too quickly for manual human control and which may further reduce a country's decision time when under attack.

Third, AI algorithms may be embedded in, and enhance, automated systems, which carry out 'dull, dirty, and dangerous' work that humans do not want to do. Modern AI capabilities, including machine learning methods, can facilitate greater autonomy beyond pre-automated capabilities towards autonomous systems.[20] Rather than having soldiers risk their lives neutralising mines or conducting intelligence, surveillance, and reconnaissance in dangerous areas, autonomous vehicles can conduct these tasks without losing human lives. Autonomous systems can also act as a force multiplier – they can patrol areas for long periods of time without needing to eat or sleep and can analyse data much quicker than human analysts, leaving military personnel free to conduct other tasks.

For these reasons, among others, militaries have used 'first-wave' autonomous systems for decades. The majority of autonomous functioning systems currently used by NATO militaries are first-wave technologies, including autonomous pre-programmed vehicles, air and missile defence systems, and autonomous missiles. Most of these

16 Paul Scharre and Michael Horowitz, *An Introduction to Autonomy in Weapon Systems* (Center for a New American Security, 2015). Accessed 20 November 2020. https://www.cnas.org/publications/reports/an-introduction-to-autonomy-in-weapon-systems.

17 Artur Kuptel and Andrew Williams, 'Multinational Capability Development Campaign (MCDC) 2013-2014, Focus Area 'Role of Autonomous Systems in Gaining Operational Access,' Policy Guidance: Autonomy in Defence Systems', NATO Allied Command Transformation, 29 October 2014. Accessed 16 November 2020. https://www.researchgate.net/figure/Figure-Suggested-definiion-for-Autonomous-Funcconing_fig1_282355597, 9.

18 Chiara Longoni and Carey K. Morewedge, 'AI Can Outperform Doctors. So Why Don't Patients Trust It?' *Harvard Business Review*, 30 October 2019. Accessed 16 November 2020. https://hbr.org/2019/10/ai-can-outperform-doctors-so-why-dont-patients-trust-it.

19 Michael Horowitz, Paul Scharre, and Alexander Velez-Green, 'A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence', 2019.

20 This report recognises that there are various, and conflicting, definitions of autonomy and autonomous systems across academic literature and military documentation. Many autonomous systems are termed as such despite lacking the ability to learn autonomously; they would not be considered modern AI technology and may be more accurately represented, in the authors' view, as automated. Many military applications are described as autonomous systems despite not having technology that is recognised as modern AI. Autonomous systems are therefore not necessarily AI-enabled, a distinction highlighted in the definitions section of this report.

systems do not rely on big data sets, ML, or DL. For instance, both the American Patriot air defence missile system[21] and the Aegis defence system, which have been in use since the 1990s and 1980s, respectively,[22] have semi-autonomous and fully autonomous modes, which allow computers to identify, target, and attack incoming threats without human approval. Additionally, a number of unmanned aerial vehicles (UAVs), including the Israeli Harop drone[23] and the American RQ-11 Raven,[24] which have been in use since the early 2000s, can fly autonomously, often relying on pre-programmed flight routes and destinations.

In recent years, as machine learning (ML) and deep learning (DL), or 'second-wave' AI methods, have rapidly improved, militaries have begun developing more advanced AI-enabled systems. For example, in 2017, the US Department of Defense began Project Maven, which used data-based AI, specifically deep learning and neural networks, to analyse drone footage in the fight against the Islamic State in Iraq and Syria (ISIS).[25] Similarly, Turkish defence companies have developed autonomous aerial vehicles that rely on ML and DL for navigation and target identification.[26] However, ML and DL methods are still relatively new, so most militaries have not yet developed systems that include them, instead relying on older autonomous systems. NATO member states must continue to develop ML and DL capabilities, as these technologies will change the way militaries operate.

This report examines both first- and second-wave AI systems currently in use by NATO militaries. To classify a system as autonomous or AI-enabled, this report relies on manufacturer, government, military, and academic sources that describe the system and does not provide a technical description of individual systems.

21 John K. Hawley, 'Patriot Wars', Center for a New American Security, 2017. Accessed 20 November 2020. https://www.cnas.org/publications/reports/patriot-wars.

22 Paul Scharre, *Army of None: Autonomous Weapons and the Future of War* (New York: W. W. Norton and Company, 2018).

23 Israel Aerospace Industries, 'HAROP: Loitering Munition System'. Accessed 22 November 2020. https://www.iai.co.il/p/harop.

24 'Raven B Group 1 UAS: Surveillance and Reconnaissance Drone', AeroVironment. Accessed 22 November 2020. https://www.avinc.com/tuas/raven.

25 Gregory C. Allen, 'Project Maven Brings AI to the Fight against ISIS', *Bulletin of the Atomic Scientists*, 21 December 2017. Accessed 17 November 2020. https://thebulletin.org/2017/12/project-maven-brings-ai-to-the-fight-against-isis/.

26 Paolo Valpolini, 'Killer Drones from Turkey'. *EDR Magazine*, 15 December 2017. Accessed 20 November 2020. https://www.edrmagazine.eu/killer-drones-from-turkey; 'Domestically-Developed Kamikaze Drones to Join Turkish Army's Inventory as of 2020', Daily Sabah, Turkuvaz Haberleşme ve Yayıncılık, 12 September 2019. Accessed 12 November 2020. https://www.dailysabah.com/defense/2019/09/12/domestically-developed-kamikaze-drones-to-join-turkish-armys-inventory-as-of-2020.

4. Common Challenges and Vulnerabilities of AI and Autonomous Systems

In examining the approach of NATO members to AI-enabled military systems, it is critical to examine the potential problems with and vulnerabilities in AI systems to understand relevant challenges and implications. While AI may help significantly improve military systems in the future, current capabilities are far from perfect, and particularly in the military sphere, mistakes may have serious consequences. Current AI technology is brittle, meaning that it only works in very specific situations. When presented with a task or environment that differs slightly from the data it was trained on or its pre-set parameters, an AI system can fail spectacularly, potentially leading to a military crisis. In a similar vein, second-wave AI algorithms like ML algorithms are only as good as the data they are trained on. ML algorithms use pre-labelled datasets to build statistical models that dictate their behaviour, but it is difficult to get high-quality, large pre-labelled datasets containing military data. Real-world military data tends to be highly classified, and there may not be enough to adequately train an ML system. Instead, many military ML algorithms would need to be trained on simulation data, which may not accurately represent the real world, especially for safety-critical systems.

In addition, even if good training data were procured, an ML algorithm is vulnerable to manipulation during its training phase. An adversary could introduce bad data to the algorithm so that it learns incorrect information – a practice known as 'data poisoning'. Even subtle changes to data can have big effects on an algorithm's performance. One study showed that when just 3 per cent of data fed to a specific algorithm was poisoned, the algorithm's classification error rate rose from 12 to 23 per cent.[27] Adversaries could conduct data poisoning 'in several ways: insiders replacing data, hacking to switch out data, including erroneous samples in openly available data, or an adversary carefully selecting its behaviours in ways that set false precedent'.[28]

Even after an AI system is fully trained on non-poisoned data, it is vulnerable to 'adversarial examples', in which adversaries manipulate live input data in subtle ways to make an AI act in ways it should not. For example, several studies have shown that small changes to an input image can drastically change an AI system's behaviour. One such study showed that adding some noise to an image of a panda caused an ML image recognition algorithm to classify the image as a gibbon with over 99 per cent certainty (while, to a human eye, the 'noisy' photo of a panda looked exactly the same as the original). It is important to note that the algorithm used in this study was trained on the largest public source dataset of images – if adversarial examples exist in robustly trained algorithms like this one, they will certainly exist in algorithms trained on smaller datasets. In the military realm, an adversary could make small physical tweaks to their own systems, making them unrecognisable to an AI-enabled system. A recent study showed that an image classifier could be tricked into identifying a machine gun as a helicopter by modifying just a few pixels.[29] Because of the lack of large military datasets, AI algorithms often rely on third-party datasets, which could be accessed by adversaries who 'could attempt to steal or replicate the systems, which they could then integrate into their own AI systems or use to find ways to neutralise the defender's systems'.[30]

How to protect AI systems against adversarial examples remains an open research question.[31] In part, this is because of the 'black box' nature of ML, especially deep neural networks, which can have billions of nodes. While the input and output of a system are observable, the system's complexity can make it difficult for humans to understand how the output is reached.[32] In the military sector, an AI system that makes an unexpected and unexplained decision can cause a catastrophe.

The inherent brittleness and vulnerabilities of AI were on full display in 2003, during Operation Iraqi Freedom, when American Patriot air and missile defence systems were involved in two fratricides while in automatic mode. In the first instance, the Patriot system identified a British fighter jet as an anti-radiation missile, in part because the jet's identification friend or foe (IFF) signal was not on, and the Patriot operators authorised the system to shoot down the jet. Just a few days later, a Patriot system identified an incoming ballistic missile that did not exist and shot down an American fighter jet.[33] In these situations, the brittleness

27 Jacob Steinhardt, Pang Wei W. Koh, and Percy S. Liang, 'Certified Defenses for Data Poisoning Attacks', in *Advances in Neural Information Processing Systems*, 2017, 3517–3529.

28 Edward Geist and Andrew J. Lohn, 'How Might Artificial Intelligence Affect the Risk of Nuclear War?'. RAND Corporation. 2018. Accessed 10 January 2021. https://www.rand.org/pubs/perspectives/PE296.html.

29 Louise Matsakis, 'Researchers Fooled a Google AI Into Thinking a Rifle Was a Helicopter', *Wired*. Conde Nast, 20 December 2017. Accessed 7 December 2020. https://www.wired.com/story/researcher-fooled-a-google-ai-into-thinking-a-rifle-was-a-helicopter/.

30 Tonin, 'Artificial Intelligence: Implications for NATO's Armed Forces', 8.

31 Horowitz et al., 'A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence'.

32 Vincent Boulanin, 'The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk: Euro-Atlantic Perspectives', Stockholm International Peace Research Institute, May 2019. Accessed 17 November 2020. https://www.sipri.org/sites/default/files/2019-05/sipri1905-ai-strategic-stability-nuclear-risk.pdf

33 Scharre, *Army of None,* 137–143.

of AI systems was evident – when their environments changed slightly (where IFF was not working, or where the radar did not bounce back the way it was supposed to), the systems failed, leading to several deaths. An army investigation of these two incidents found that the Patriot community had a culture of 'trusting the system without question'.[34]

A number of studies have found that humans often have 'automation bias', whereby they overtrust computer systems, even when they know they are flawed. For example, one study showed that pilots given good, but imperfect autopilots in a flight simulation tend to make more mistakes and are 'more likely to miss problems unless explicitly prompted by the autonomous system', even making decisions that contradict their training if prompted to do so by a computer.[35] Automation bias may lead human operators to trust a flawed system, even when the computer system contradicts the operator's own training.

34 Ibid., 144.

35 Horowitz et al., 'A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence'.

5. NATO Activities: Development of AI Applications for the Military

This section will discuss how NATO has publicly approached military AI. NATO's public thinking on AI is still in a relatively early stage; however, NATO has taken several steps to address the role of AI in NATO. So far, NATO has adopted an AI strategy,[36] started to develop several AI-related projects, published several white papers that discuss military AI,[37] and hosted a number of relevant discussions on AI.[38] Defence ministers have previously endorsed the 2019 Emerging and Disruptive Technologies (EDT) 'Roadmap' and 2021 EDT Coherent Implementation Strategy, which have helped 'set the agenda to integrate and bolster NATO's work on AI'.[39]

In October 2021, NATO adopted an AI strategy,[40] which commits NATO "to collaboration and cooperation among Allies on any matters relating to AI for transatlantic defence and security" in order to "maintain NATO's technological edge." [41] The strategy itself has not been publicly released; however, NATO released a summary of the strategy in a press release.[42] The strategy is meant to accelerate the adoption of AI in NATO militaries by "building on the existing adoption efforts of several NATO and Allied bodies" [43] and has four main goals:

- → To encourage responsible development and use of AI for Allied defence and security purposes;
- → To facilitate mainstream AI adoption across Allies, accelerating capability development and enhancing operability within the Alliance;
- → To focus on effective AI innovation and address additional policy considerations, including the operationalisation of the agreed principles of responsible use; ; and
- → To defend against the malicious use of AI by state and non-state adversaries." [44]

The strategy notes that NATO must work to integrate AI into military systems in an interoperable way and stresses the importance of cooperation between NATO, the private sector, and academia in developing AI for defence purposes. NATO and its Allies will regularly conduct high level dialogues on AI, engaging with technology companies to "a common understanding of the opportunities and risks arising from AI." [45] Finally, NATO's AI strategy outlines NATO's six principles of responsible use for AI: lawfulness, responsibility and accountability, explainability and traceability, reliability, governability, and bias mitigation. These principles will help steer NATO's military AI efforts "in accordance with our values, norms, and international law." [46]

In addition to its AI strategy, NATO has published several white papers that discuss military AI. In March 2020, NATO's Science and Technology Organization (STO) published a document titled 'Science and Technology Trends 2020–2040: Exploring the S&T Edge',[47] which identified AI and autonomy as two emerging or disrupting technologies that will affect militaries in the future. The document states that AI will likely have a 'revolutionary'[48] impact on NATO operations, as it is increasingly integrated into a number of systems, including 'combat models & simulation, enterprise systems, decision support systems, cyber defence systems... virtual/augmented reality, quantum computing, autonomy... space, materials research, manufacturing &

36 Zoe Stanley-Lockman and Edward Hunter Christie,, "An Artificial Intelligence Strategy for NATO." Note: this strategy was released after the Authors wrote the rest of the report.

37 Edward H. Christie, 'Artificial Intelligence at NATO: Dynamic Adoption, Responsible Use', *NATO Review*, 24 November 2020. Accessed 11 December 2020. https://www.nato.int/docu/review/articles/2020/11/24/artificial-intelligence-at-nato-dynamic-adoption-responsible-use/index.html?utm_source=twitter; Erica Pepe, 'NATO and Collective Thinking on AI', International Institute for Strategic Studies (IISS), 13 November 2020. Accessed 11 December 2020.

38 George Leopold, 'NATO Targets AI Interoperability', EnterpriseAI, 2 November 2020. https://www.enterpriseai.news/2020/11/02/nato-targets-ai-interoperability/; 'Artificial Intelligence: A Game Changer for the Military', NATO Allied Command Transformation. 25 October 2019. https://www.act.nato.int/articles/artificial-intelligence-game-changer-military; NATO, 'Cooperation on Artificial Intelligence Will Boost Security and Prosperity on Both Sides of the Atlantic, NATO Deputy Secretary General Says', 28 October 2020, accessed 9 January 2021, https://www.nato.int/cps/en/natohq/news_179231.htm; Corrie Poland, 'NATO Focuses on Big Data and Artificial Intelligence', Air Force Global Strike Command AFSTRAT-AIR. United States Air Force, 12 June 2018. Accessed 2 December 2020, https://www.afgsc.af.mil/News/Article-Display/Article/1549257/nato-focuses-on-big-data-and-artificial-intelligence/.

39 Zoe Stanley-Lockman, 'Military AI Cooperation Toolbox', Center for Security and Emerging Technology, August 2021. Accessed 10 January 2021. https://cset.georgetown.edu/publication/military-ai-cooperation-toolbox/, 33.

40 Zoe Stanley-Lockman and Edward Hunter Christie,, "An Artificial Intelligence Strategy for NATO."

41 NATO, "Summary of the NATO Artificial Intelligence Strategy," North Atlantic Treaty Organization, October 22, 2021, Accessed December 2, 2021, https://www.nato.int/cps/en/natohq/official_texts_187617.htm.

42 Ibid.

43 Ibid.

44 Ibid.

45 Ibid.

46 Ibid.

47 NATO Science and Technology Organization, 'Science and Technology Trends 2020–2040: Exploring the S&T Edge'.

48 Ibid, 14.

logistics', [49] big data analytics, and autonomous vehicles. AI will also be integrated into sensors, where it will be used 'to pre-process information and provide adaptive use of frequencies (e.g. cognitive radar)', which will 'paradoxically lead to a decrease in communication traffic'. [50] The document predicts that 'AI will also have a significant effect on the conduct of NATO S&T efforts as meta-analyses of existing research will expose new discoveries, identify promising research areas and provide improved S&T tools to support further research'. [51]

The document further outlines the areas where AI will have the most impact and improve NATO forces:

→ **C4ISR**: AI will enable C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) in a number of ways. Autonomous vehicles will conduct ISR, collecting vast amounts of data and accessing areas too dangerous for human access; AI algorithms will consolidate and analyse data (e.g. detect patterns of life, conduct human terrain mapping and social network analysis) from a number of sources and sensors and provide decision support for human operators; AI will be used for image recognition and target discrimination; AI will enhance early warning systems and serve as a virtual assistant (like Google Home or Alexa) to human operators.

→ **Weapons and Effects**: AI has potential use in a number of existing and future weapons systems, including 'in cross-cueing, trajectory planning, collision avoidance, swarming, weapon selection, battle damage assessment and effects coordination'. [52]

→ **Autonomous Vehicles (UxV)**: AI will further the development of autonomous and unmanned vehicles by enabling 'trajectory planning, collision avoidance/ swarming, operator assistance (e.g. one operator controlling multiple UxVs)... dynamic mission planning for autonomous systems (e.g. navigation, data collection, environmental characterisation and adaptive sensing)', and navigation. AI will also enable fully autonomous 'explosive ordnance disposal in urban areas' and 'long duration unmanned underwater vehicles'. [53]

→ **Capability Planning**: 'AI will support the development of analytical solutions to assist in long term planning within NATO, including supporting complex decision-making that cuts across traditional internal boundaries; assisting assessments of complex factors and effects chains for decision-makers'. [54]

→ **CBRN**: AI may improve rapid detection, identification, and monitoring of CBRN (chemical, biological, radiological, and nuclear defence) threats through sensor positioning and integration and data fusion and interpretation.

→ **Medical**: AI will improve medical support for military personnel by assisting in 'developing evidence-based clinical knowledge, evidence-based diagnostics and treatment best practices to reduce morbidity and mortality and maintain/recover essential functions in the face of hazards from across the mission spectrum'. It will also be able to 'provide automated decision support and diagnostic support tools to assist medics in the field who are dealing with novel trauma situations'. [55]

→ **Enterprise Management**: AI will make enterprise resource management more effective and efficient by using 'advanced [data] analytics and evidence-based decision making'. It can help manage finances by assisting 'in cost analysis, assessment of economic impacts and drivers, and the provision of timely evidence-based decision support'. [56]

→ **Logistics**: AI will be able to 'minimise equipment downtime, minimise system failures, improve inventory and repairs management etc.'.[57] The commercial sector already uses AI to improve logistical efficiency,[58] so it will be easily transferable to the military sector.

→ **Cyber and Information Space**: AI will play a role in building resilient autonomous networks and cyber warfare that will assess and interpret vast amounts of sensor and intelligence data and detect, evaluate, and respond to the environment.

→ **Training**: 'AI systems (especially when paired with virtual/augmented reality systems) have the potential to improve individual and customised training through real-time adaptation to human behaviour and the generation of customised training environments or scenarios'.

The document also notes ways in which AI systems will be used by adversaries to undermine NATO forces and vulnerabilities present in AI systems:

49 Ibid, 15.
50 Ibid, 15.
51 NATO Science and Technology Organization, 'Science and Technology Trends 2020–2040: Exploring the S&T Edge', 15.
52 Ibid, 55.
53 Ibid, 55.
54 Ibid, 55.
55 Ibid, 55.
56 Ibid, 56.
57 Ibid, 56.
58 'Artificial Intelligence in Logistics: A Collaborative Report by DHL and IBM on Implications and Use Cases for the Logistics Industry', DHL Trend Research, DHL Customer Solutions and Innovation, 2018. http://dhl.lookbookhq.com/ao_thought-leadership_digital-analytics-2/research-report_artificial-intelligence-in-logistics.

→ **Cyber**: 'AI systems are particularly vulnerable to cyberattacks, whereby small, deliberate changes may lead to erroneous recommendations or sub-optimal actions'.

→ **Information**: Advances in speech processing and deep learning (e.g. Generative Adversarial Networks) 'are likely to allow the realistic simulation of friendly and enemy personnel over communications links and broadcast media (i.e. deep fakes)'. Especially when combined with twitter-bots and social media hacks, AI-enabled speech generation and deep fakes 'will greatly increase the scale and effectiveness of hybrid attacks, whether by near-peer or asymmetric threats'.

→ **Aberrant Behaviour**: AI systems often act in an unpredictable fashion. While this unexpected behaviour can be a strength (e.g. creating entirely new strategies), it is also a liability.

→ **Improvised Explosive Devices**: 'Increasingly intelligent, learning systems will enable new generations of improvised explosive devices, less susceptible to traditional countermeasures'.

NATO's Science and Technology Committee Sub-Committee on Technology Trends and Security (STCTTS) released another document covering AI titled 'Artificial Intelligence: Implications for NATO's Armed Forces',[59] which outlines the opportunities, challenges, and uncertainties of AI in the armed forces. This document describes two main applied areas for opportunity (although it notes a number of other areas that will be affected by AI): information and decision support and robotic autonomous systems (RAS).

→ Information and decision support: AI will allow militaries to quickly analyse and act on data. Fast analysis and action will improve reaction times of defensive systems, deliver information to decision makers more quickly, quickly discover cyber intrusions, help identify disinformation campaigns, provide better data visualisation, extract objects of interest from data feeds (e.g. image recognition), establish 'common operating pictures' from information from many sources, highlight abnormalities in data, and provide insights into adversarial behaviour.

→ RAS: At present, mostly used for 'explosive-ordinance disposal; counter-mine operations on land or underwater; rescue missions; logistical support; and even combat operations'. AI has become a 'backbone technology' for these systems. As such systems become more popular, they may 'reduce a unit's personnel number substantially', and 'swarms of robotic autonomous systems could be employed to overwhelm anti-access/area-denial defence postures'.[60]

The STCTTS document notes that there will be a number of challenges, both non-technical and technical, in developing AI for military applications. Non-technical challenges include investment, innovation, and workforce challenges. Militaries will need to invest sufficient capital into research and development, while armed forces 'must become better at adopting and integrating technologies from the non-defence commercial sector' and find ways to recruit the top AI experts, many of whom are offered much higher salaries in the private sector.

NATO has several AI-enabled projects under development. One project is the Military Uses of Artificial Intelligence, Automation, and Robotics (MUAAR). The MUAAR project is US-led and will investigate the uses of AI, automation, and robotics in areas such as the electromagnetic spectrum, integrated air and missile defence, logistics, and the space, cyberspace, air, land, and maritime domains.[61] Another project is NATO's Data Science Centre. In October 2019 the NATO Communications and Information Agency (NCI Agency) announced that it was developing a Data Science Centre to organise the agency's data science expertise.[62] The NCI Agency has sponsored work on machine learning and AI,[63] so it is likely that data collected in this new Data Science Centre could be used to develop NATO AI capabilities. Additionally, in 2020, NATO established the Maritime Unmanned Systems Innovation Advisory Board, which has focused on developing a number of projects focused on unmanned and autonomous maritime systems.[64] AI activity is also likely to be captured under broader innovation initiatives, such as through the intended creation of both the civil-military Defence Innovation Accelerator and the NATO Innovation Fund, as announced at the June 2021 Brussels summit.[65]

NATO will likely not be the driving force behind member states' military AI development for several reasons. NATO does not have the authority to force members to follow certain strategies or act in any particular way. NATO is a large

59 Tonin, 'Artificial Intelligence: Implications for NATO's Armed Forces'.

60 Ibid., 3–4.

61 NATO Allied Command Transformation, '2020 Fact Sheet: Military Uses of Artificial Intelligence, Automation, and Robotics (MUAAR)', NATO Allied Command Transformation. February 2020. Accessed 4 December 2020. https://www.act.nato.int/application/files/5515/8257/4725/2020_mcdc-muaar.pdf.

62 NCI Agency, 'NATO Community Discusses Data, Cloud and Securing the Alliance at NIAS', NATO Communications and Information Agency, 15 October 2019. Accessed 4 December 2020. https://www.ncia.nato.int/about-us/newsroom/nato-community-discusses-data--cloud-and-securing-the-alliance-at-nias-.html.

63 NATO Communications and Information Agency, 'NATO Agency Contributes Expertise to Machine Learning Hackathon', 28 February 2020. Accessed 9 January 2021. https://www.ncia.nato.int/about-us/newsroom/nato-agency-contributes-expertise-to-machine-learning-hackathon.html.

64 NATO, 'New Innovation Advisory Board to Boost NATO Maritime Unmanned Systems Initiative', 11 May 2020. Accessed 7 September 2021. https://www.nato.int/cps/en/natohq/news_175660.htm.

65 NATO, 'Brussels Summit Communiqué', Issued by the Heads of State and Government participating in the meeting of the North Atlantic Council in Brussels 14 June 2021. NATO, 14 June 2021. Accessed 7 September 2021. https://www.nato.int/cps/en/natohq/news_185000.htm.

alliance that requires consensus to make decisions. With 30 members, consensus-building takes time, particularly on contentious security challenges. Additionally, member states are often hesitant to share sensitive information with all members of the alliance. Allies may hesitate to share information that either offers them a competitive advantage in conflict or, conversely, may demonstrate a weakness in their security posture. These factors will be increasingly pertinent as a limitation to sharing AI applications or training datasets in the future. Rather, NATO holds the capacity to play the role of a *facilitating* force for an Alliance-level approach to military AI.[66] NATO can host discussions between member states on military AI, guide member states' thinking on military AI, and provide opportunities for member states to collaborate on the development of military AI. Standardisation is also one area in which NATO is uniquely positioned; the NATO Standardisation Office is the largest military standardisation body and is therefore well-placed to determine 'a natural convening point to see which civilian standards can apply to the military realm, as well as identify niche areas where military AI standards require dedicated attention'.[67]

Recognising that NATO does not represent a 'silver bullet' to either capacity-building or responsible deployment of military AI technologies, it is important to acknowledge a number of other potential actor groupings that may influence the military AI landscape. The private sector now represents the forefront of AI innovation, including in the military sphere; private-public partnerships are a theme championed across national and international defence strategies. States with more advanced military AI capabilities may choose alternative networks as a way to share information with their most trusted colleagues; the Five Eyes alliance is one such example of a high-trust network. The US Partnership for Defense[68] will also be discussed within the US country profile in Appendix A. As AI is a dual use technology, any norms-building processes or interpretations of international law will likely draw on discussions happening at the United Nations, particularly at relevant UN working groups, while the European Union and its international counterparts are likely to have a strong impact on trade and innovation of wider AI investment. The UN Group of Governmental Experts (GGE) on emerging technologies in the area of lethal autonomous weapons systems (LAWS), established in 2016 under the Convention on Certain Conventional Weapons (CCW), is one example of ongoing efforts to facilitate intergovernmental consensus on the legal, technological, and military aspects of these technologies.[69]

66 The authors are grateful to a number of anonymous NATO-employed experts who offered relevant insights through their participation in non-classified interviews. Interviews were conducted from September to December 2020.

67 Zoe Stanley-Lockman, 'Military AI Cooperation Toolbox', 34.

68 Patrick Tucker, 'France, Israel, S. Korea, Japan, Others Join Pentagon's AI Partnership', Defense One, 16 September 2020, https://www.defenseone.com/technology/2020/09/france-israel-s-korea-japan-others-join-pentagons-ai-partnership/168533/.

69 Frank Saure, 'Lethal Autonomous Weapons Systems', in The Routledge Social Science Handbook of AI (Routledge, 2021), 237–250.

6. Analysis: NATO Member States' Approaches to AI Applications in the Military

This section will broadly discuss the role of AI in NATO member states' militaries, examining why countries have or have not published national or military AI strategies and how NATO countries work together to develop military AI. For a detailed snapshot of how each member state has approached and invested in AI and/or autonomous systems innovation and deployment, please see 'Appendix A: Country Profiles'.

Currently, 23 of 30 NATO countries have adopted national AI strategies,[70] with Bulgaria, Croatia, Iceland, and Slovenia actively developing their own national AI strategies.[71] While some countries' national AI strategies mention military applications of AI, most of the documents ignore it or mention it only in passing. Only two countries, the US and France, have published standalone military AI strategies; however, the Netherlands and Hungary are both in the process of writing military AI strategies. Several countries have published other military documents that discuss AI. For example, Germany's army published a document outlining how the German army will use AI,[72] and Turkey's military published a document discussing Turkish military technology that stressed the importance of AI.[73]

There are a number of reasons to publish a military AI strategy. Military AI strategies can spur national action and encourage collaboration in the area of AI. Some countries may publish military AI strategies in an attempt to shape international norms for the use of military AI. For instance, the French military AI strategy emphasises the importance of international law when using military AI. Publishing a military AI strategy brings national attention to military AI and can encourage both public and private sector innovation in the sphere, especially when the strategy is paired with increased government investment in AI innovation. It also brings international attention to military AI, which can encourage international collaboration. The American military AI strategy stresses the importance of working with international allies on military AI, while the French strategy goes one step further and explicitly names nations with which France would like to collaborate on military AI.

6.1. Collaboration

NATO countries have already begun to collaborate internationally to develop military AI, with both NATO member states and partner countries. One of the largest collaboration groups, the AI Partnership for Defense (PfD), was set up by the US Department of Defense Joint Artificial Intelligence Center (JAIC). It includes NATO countries France, Canada, Estonia, Denmark, the UK, and Norway, as well as non-NATO countries the Republic of Korea, Australia, Sweden, Finland, Israel, and Japan. The PfD first met in September 2020 to discuss lessons learned, best practices, and how to shape what responsible AI looks like in the military.[74] JAIC hopes that the PfD will be 'an enduring forum for dialogue among like-minded partners to advance our shared interests in artificial intelligence and help shape the future of our defence cooperation for the digital era'.[75]

While the PfD is a forum for discussing more general topics like best practices and ethics, NATO countries also often work with other countries on specific AI-related projects. For example, with the support of the Estonian Ministry of Defence, Estonian defence company Milrem has been working with the Dutch Robotic and Autonomous Systems Unit to develop the THeMIS unmanned ground vehicle (UGV), which has a number of autonomous features.[76] Similarly, France, Germany, and Spain are collaborating on the Future Combat Air System (FCAS), which aims to create an AI-enabled sixth-generation fighter aircraft,[77] and Poland, Germany, and the Netherlands are all working together on an AI-enabled electronic warfare project.[78]

Thus far, there have been few NATO-wide collaborative projects on military AI (other than the few described in the previous section). Instead, NATO countries seem to prefer to partner with a few close allies, both in and out of

70 Greece, Croatia, Albania, Iceland, Montenegro, North Macedonia, and Slovenia have not yet published national AI strategies.

71 This finding is based on open-source research by the authors and can be examined according to NATO member state in Appendix A: Country Profiles.

72 German Army Concepts and Capabilities Development Center, 'Artificial Intelligence in Land Forces: A Position Paper by the German Army Concepts and Capabilities Development Center', Bundeswehr, November 2019, https://www.bundeswehr.de/resource/blob/156026/3f03afe6a20c35d07b0ff56aa8d04878/download-positionspapier-englische-version-data.pdf.

73 '2018–2022 Savunma Sanayii Sektoral Strateji Dokumani' [in Turkish], Turkish Presidency of Defence Industries. https://www.ssb.gov.tr/Images/Uploads/MyContents/F_20190402102925477924.pdf.

74 Patrick Tucker, 'France, Israel, S. Korea, Japan, Others Join Pentagon's AI Partnership'.

75 JAIC Public Affairs, 'JAIC Facilitates First-Ever International AI Dialogue for Defense', Joint Artificial Intelligence Center. 16 September 2020. Accessed 23 December 2020. https://www.ai.mil/news_09_16_20-jaic_facilitates_first-ever_international_ai_dialogue_for_defense_.html.

76 Harry Lye, 'Estonia and the Netherlands Sign Joint Milrem THeMIS Order', Army Technology, 29 September 2020, https://www.army-technology.com/news/deal-news/estonia-and-the-netherlands-sign-joint-milrem-themis-order/.

77 Airbus, 'Future Combat Air System (FCAS): Shaping the Future of Air Power', accessed 4 January 2021, https://www.airbus.com/defence/fcas.html.

78 European Defence Agency, 'Stronger Communication and Radar Systems with Help of AI', 31 August 2020, accessed 30 November 2020, https://www.eda.europa.eu/info-hub/press-centre/latest-news/2020/08/31/stronger-communication-radar-systems-with-help-of-ai.

the alliance. There are several reasons that countries may be reluctant to work on a NATO-wide project. First and foremost, with 30 member states, NATO is a large alliance, and it can be difficult to work effectively with such a large group. While several member states have developed their own views on how AI should or should not be used in the military, with the US, UK, and France examples of states who have demonstrated investment in military AI capabilities, a number of other members have yet to issue public statements or highlight targeted investment towards military AI innovation.

Second, bilateral tensions between NATO allies may make countries unwilling to share sensitive information and technology with other members. France has stressed the importance of self-reliance in the military sphere, including in the military AI sphere. Noting that the US and China are currently leading the world in AI, France's military AI strategy states, 'France cannot resign itself to being dependent on technologies over which it has no control. In the specific case of military AI, and in order to ensure the confidentiality and control of our information, it is essential that we preserve our technological sovereignty'.[79]

Third, many NATO countries do not have the capabilities to contribute to a joint military AI project, so countries who want to contribute may turn to non-NATO allies with more advanced AI capabilities. For instance, Iceland has no standing army, while other NATO allies like Albania and Montenegro have only a few thousand active military personnel and virtually no investment in military AI.

Another issue NATO countries may consider when developing AI-enabled and autonomous military systems is public opinion. According to a study that surveyed people in 26 countries,[80] 61 per cent of respondents say they opposed lethal autonomous weapons systems.[81] Many militaries will feel pressure both to *develop* AI-enabled military systems as their adversaries advance their own AI capabilities and to *cease developing* AI-enabled military systems if their citizens feel these systems are unethical. Militaries will need to manage a balancing act between maintaining technological capabilities and listening to their citizens' opinions.

There are several benefits to collaborating with other countries on military AI. First, second-wave AI like ML and DL rely on large, high-quality data sets in order to be effective. If many countries work together on military AI, they will be able to pool their data in order to create large enough data sets for ML algorithms. Working together to create data sets is especially important in the military sphere, where data may be hard to access and use, particularly due to classification requirements. Second, because AI is a relatively new field, there are a limited number of people with AI expertise in countries' militaries. In fact, recruiting and fostering AI experts is one of the main goals of most countries' AI strategies.[82] By working together, countries can share AI knowledge and bring together the limited number of experts to find better ways to use AI in the military. Third, by working across NATO, countries could ensure the interoperability of national military AI-related capabilities. NATO member states work together in military operations and exercises, so it is important for their future military AI systems to be able to work together.

79 'Artificial Intelligence in Support of Defence: Report of the AI Task Force', Ministere des Armées, September 2019, 9–10.

80 Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, France, Germany, Great Britain, Hungary, India, Israel, Italy, Japan, Mexico, the Netherlands, Peru, Poland, Russia, South Africa, South Korea, Spain, Sweden, Turkey, and the United States.

81 Ipsos, 'Six in Ten (61%) Respondents Across 26 Countries Oppose the Use of Lethal Autonomous Weapons Systems', 21 January 2019. Accessed 10 January 2021. https://www.ipsos.com/en-us/news-polls/human-rights-watch-six-in-ten-oppose-autonomous-weapons.

82 For example, see 'Artificial Intelligence in Land Forces', 13; 'Artificial Intelligence in Support of Defence', 21.

7. Categorisation of AI Applications and Autonomous Systems in the Military

Twenty-five NATO countries, with the exception of Albania, Luxembourg, Montenegro, Slovakia, and Slovenia, use some AI-enabled and autonomous systems in their militaries. AI systems generally fall into four categories: Autonomous Vehicles; Autonomous Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft; Data Analytics; and Logistics and Personnel Management. Of course, these categories do not represent the extent to which AI can be used in military systems. In the future, as outlined in NATO publications, AI will be integrated into command and control systems, healthcare management, decision support, and cybersecurity.

Other reports on military AI have used slightly different categorisations and use terminology in different ways. For example, the SIPRI report 'Mapping the Development of Autonomy in Weapon Systems' uses five categories to describe existing autonomous military systems: air defence systems; active protection systems; robotic sentry weapons; guided munitions; and loitering weapons.[83] The authors of this report chose the four categories we use to describe AI military systems based on the systems that exist in NATO member state militaries specifically. Our categories may also differ from other reports because this report does not focus exclusively on physical weapon systems. This report also examines non-kinetic AI-enabled systems like Project Maven, so the report includes the 'Data Analytics' and 'Logistics and Personnel Management' categories.

The majority of the AI systems in NATO militaries fall into the 'Autonomous Vehicles' and 'Autonomous Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft' categories, likely because the technology that enables these categories has been around much longer. While autonomous vehicles, autonomous air and missile defence systems, and autonomous missiles rely more heavily on first-wave AI, data analytics and logistics tend to rely on second-wave AI, which is a much newer field. The rest of this section will discuss these four categories and potential problems with and vulnerabilities in AI-enabled military systems.

7.1. Autonomous Vehicles

Autonomous vehicles are perhaps the most prevalent autonomous military systems. They include unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and unmanned underwater vehicles (UUVs). Unmanned vehicles with some degree of autonomy have existed for several decades, though they have evolved significantly since the late 1990s. Rather than merely relying on pre-determined flight paths, many autonomous vehicles today use ML to operate.[84] Militaries use autonomous vehicles for a number of purposes, including mine counter measures,[85] ISR,[86] target acquisition,[87] research,[88] and as weapons themselves.[89]

Perhaps the most controversial use of autonomous vehicles is as weapons. Several NATO states, including the US, Germany, Poland, and Turkey, use 'loitering munitions', which are UAVs equipped with warheads that operate autonomously. They fly to a predetermined location and loiter until a target is acquired, at which point the UAV collides with the target, setting off its warhead.[90]

7.2. Autonomous Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft

This category includes a broad swath of technologies, including autonomous air and missile defence systems, autonomous missiles, and AI-enabled aircraft.

Autonomous and semi-autonomous air and missile defence systems have been around for decades. For instance, the American-made Patriot air defence system, which has an autonomous mode and is in use by a number of NATO countries, was first used in the early 1990s. Similarly, the Dutch-made ship-mounted, short-range air defence system Goalkeeper and the American-made Aegis ballistic missile defence system, both of which can operate autonomously, were developed in the mid-1970s.

83 Vincent Boulanin and M. Verbruggen, 'SIPRI Mapping the Development of Autonomy in Weapon Systems' (Solna: SIPRI, 2017).

84 See Turkish country profile for more information: Ensar Şeker and İhsan Burak Tolga, 'National Cyber Security Organisation: Turkey', CCDCOE, 2018. https://ccdcoe.org/library/publications/national-cyber-security-organisation-turkey/.

85 UMS Skeldar, 'Latest Activities at UMS Skeldar', 8 July 2020. Accessed 20 November 2020. https://umsskeldar.aero/eca-group-selects-the-uav-skeldar-v-200-within-the-belgium-naval-robotics-mine-countermeasures-drones-system-for-the-belgian-and-royal-netherlands-navies/.

86 US Department of Defense, 'RQ-11B RAVEN Small Unmanned Aircraft Systems (SUAS)', US Army. 4 November 2014. Accessed 20 November 2020. https://www.army.mil/article/137604/rq_11b_raven_small_unmanned_aircraft_systems_suas.

87 Ibid.

88 'REMUS-100 Automatic Underwater Vehicles', Naval Technology. Verdict Media Limited, 4 January 2021. Accessed 8 January 2020. https://www.naval-technology.com/projects/remus-100-automatic-underwater-vehicle.

89 WB Group, 'WARMATE Loitering Munitions', 8 July 2020. Accessed 6 January 2021, https://www.wbgroup.pl/en/produkt/warmate-loitering-munnitions.

90 Dan Gettinger and Arthur Holland Michel, 'Loitering Munitions'.

Autonomous missiles are missiles that can operate in a 'fire and forget' fashion, meaning that once the missile has been fired, it can find and navigate towards its own targets. Examples of autonomous missiles include the UK's Brimstone missile and Norway's Naval Strike Missile/Joint Strike Missile (NSM/JSM). Unlike other guided missiles, Brimstone and NSM/JSM are not assigned a specific target; instead, they are assigned a target area, where the missiles themselves select and attack targets. This report will also include more traditional 'fire and forget' missiles like the French Mistral 2 anti-aircraft missile as autonomous.

Several 'next generation' aircraft programs include AI components. For example, Lockheed Martin's F-35 Lightning II fifth-generation fighter aircraft program,[91] which is used or will be used by a number of NATO countries, has several AI components, including decision support and data analytics systems.[92] In the future, the F-35 will likely also use AI to control unmanned drone 'wingmen', which could carry weapons, conduct ISR, or test enemy air defences.[93] Similarly, two European sixth-generation aircraft projects, the Future Combat Air System (FCAS) and BAE Tempest, will include AI components. BAE Tempest will have an AI-enabled autonomous flight system that would enable the aircraft to fly without a pilot,[94] and FCAS will use AI and neural networks[95] to allow the aircraft to team with unmanned platforms,[96] share information with other actors in a 'combat cloud',[97] and assist in pilot situational awareness and decision-making.[98]

7.3. Data Analytics

Data analytics is a sector that could be significantly improved by integrating second-wave AI systems. Currently, many military systems collect vast amounts of data; however, that data is only effective if it is analysed.[99] Countries are using AI to analyse a variety of data types, including drone footage,[100] satellite images,[101] signals intelligence,[102] and underwater acoustics.[103] They are using data analysis to improve everything from cyber defence[104] and early crisis detection,[105] to target recognition,[106] to situational awareness.[107] For example, the French military has been working on using ML to analyse satellite images.108 France has also developed the TALIOS system, which attaches to the F4 Rafale fighter jet[109] and uses AI to analyse sensor and image data for situational awareness, automatic target detection and recognition, and ISR.[110]

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7.4. Logistics and Personnel Management

Many countries use or plan to use AI to improve logistical problems such as predictive maintenance, procurement, and acquisition, as well as personnel management and healthcare. Predictive maintenance is the most common logistical problem that countries are using AI to solve. Several NATO countries, including Spain[111] and France,[112] have begun using AI to monitor fleets of ships and aircraft to predict when each system will need maintenance. Thus far, countries have not begun using AI for personnel management and military healthcare; however, countries like France and North Macedonia[113] have expressed plans to do so.

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113 For more information, see Appendix A: Country Profiles.

8. Conclusion

AI and autonomous systems will play an increasingly large part in enabling future military activities. AI-enabled systems will make warfare faster and more effective by several metrics. ML will be especially influential, as militaries use it to improve a wide variety of systems, including autonomous vehicles, air and missile defence systems, ISR, and logistics support.

NATO member states are, to varying extents, investing and exploring AI-enabled technology and autonomous military systems. There is an element of pressure to this, with significant evidence that Russia and China are already actively and aggressively developing these systems. The consequences of falling behind technologically *could* be catastrophic should AI-enabled systems live up to the current expectations of many.

Military AI and autonomous systems should not be underestimated, and incremental implementations can be leveraged to great effect. Militaries around the world have begun integrating AI-enabled and autonomous systems into their militaries, especially in the categories discussed in this paper – autonomous vehicles, autonomous air and missile defence systems, data analytics, logistics, personnel management, and healthcare. Whenever possible, NATO should facilitate cooperation and information sharing between its members to ensure their military systems remain cutting-edge. It is important for NATO countries to work together to ensure that their military systems are interoperable and secure.

When developing AI-enabled and autonomous systems, it is imperative that militaries consider security. AI systems are brittle, opaque, and reliant on good data, and any failure in an AI military system could have catastrophic consequences.

9. Appendix A: Country Profiles

Appendix A can be found in a separate document titled "Artificial Intelligence and Autonomy in the Military: An Overview of NATO Member States' Strategies and Deployment: Appendix A – Country Profiles."

10. Appendix B: Graphics and Tables

Figure 1: AI Strategies and Programmes by Country

Country	AI Strategy	AI Military Strategy	Programmes
Albania	no	no	
Belgium	yes	no	A-18M, B-HUNTER, F-35, Harpoon Block II, REMUS 100, Skeldar V-200, SWORD
Bulgaria	yes	no	AMRAAM, RQ-11 RAVEN
Canada	yes	no	ADATS, Boatswain's Mate, Double Eagle SAROV, F-35, Gavia, Harpoon Block II, Iver, Phalanx, REMUS 100, ScanEagle, Skeldar V-200
Croatia	in progress	no	REMUS 100
Czech Republic	yes	no	Puma 3, RQ-11 RAVEN, ScanEagle, Skylark I-LEX, SPYDER
Denmark	yes	no	AMRAAM, Double Eagle SAROV, F-35, Gavia AUV, Harpoon Block II, MU90 IMPACT, Puma 3, RQ-11 RAVEN
Estonia	yes	no	Mistral 2, Puma 3, RQ-11 RAVEN, RQ-4 Global Hawk, THeMIS
France	yes	yes	A27-M, ARCHANGE, Automatic Imaging Target Acquisition, BlueScan, Future Combat Air System, MU90 IMPACT, Nerva, SAMP/T, SWORD, Skylark I-LEX, TALIOS, THeMIS, nEUROn
Germany	yes	army-specific	AWISS, Barracuda, CRAI, Future Combat Air System, Harop, Harpoon Block II, Kalætron Attack, LUNA, MANTIS, MU90 IMPACT, Patriot, Puma 3, SABUVIS, SeaRAM, Skeldar V-200, THeMIS
Greece	in progress	no	Harpoon Block II, nEUROn, Patriot, SeaRAM
Hungary	yes	in progress	AMRAAM, Mistral 2, RQ-11 RAVEN
Iceland	in progress	no	Gavia
Italy	yes	no	BAE Tempest, DARDO, F-35, MU90 IMPACT, RQ-11 Raven, SAMP/T, ScanEagle, nEUROn
Latvia	yes	no	A9-M, Husky, Puma 3, THeMIS
Lithuania	yes	no	NASAM
Luxembourg	yes	no	
Montenegro	no	no	
North Macedonia	no	no	RQ-11 RAVEN
Norway	yes	no	Aegis, F-35, HUGIN, Joint Strike Missile, Naval Strike Missile, REMUS 100, THeMIS
Poland	yes	no	CRAI, F-35, Gavia, Harpoon Block II, MU90 IMPACT, Naval Strike Missile, Patriot, Perun, SABUVIS, ScanEagle, WARMATE
Portugal	yes	no	AR-4, Gavia, Goalkeeper, Harpoon Block II, Iver, Phalanx SWORDFISH, SeaCon

Romania	yes	no	AMRAAM, Patriot, RQ-11 RAVEN
Slovakia	yes	no	
Slovenia	in progress	no	
Spain	yes	no	Aegis, Barracuda, BlueScan, Future Combat Air System, Harpoon Block II, Patriot, RQ-11 RAVEN, SWORD, ScanEagle, nEUROn
The Netherlands	yes	in progress	A-18M, CRAI, F-35, Goalkeeper, Harpoon Block II, Mission Master, Patriot, REMUS 100, RQ-11 RAVEN, ScanEagle, Skeldar V-200, THeMIS
Turkey	yes	no	AKINCI, ALPAGU, Albatros-K, Anka-S, Harpoon Block II, KARGU, PULAT, TB2, TF-X, TOGAN, Wattozz
UK	yes	no	Project Nelson, THeMIS, Phalanx, REMUS 100, F-35, A27-M, RQ-11 Raven, Watchkeeper, Taranis, ScanEagle, Puma 3, VIKING 6x6, Manta, MAST-9, MAST-13, Tempest, Brimstone
US	yes	yes	Project Maven, Patriot, Aegis, F-35, THeMIS, SABUVIS, Phalanx, Gavia, RQ-11 Raven, SeaRAM, MQ-9 Reaper, ARTUμ, Iver, ScanEagle, SeaHunter, C-DAEM, LIMS IV, Project Salus

Figure 2: Autonomous Vehicles

Programme	Type	Developer	NATO Countries
A-18M	Underwater	ECA Group	Belgium, Netherlands
A27-M	Underwater	ECA Group	France, UK
A9-M	Underwater	ECA Group	Latvia
AKINCI	Aerial	Baykar	Turkey
Albatros-K	Surface	ASELAN	Turkey
ALPAGU	Aerial	STM	Turkey
Anka S	Aerial	Turkish Aerospace Industries	Turkey
AR-4	Aerial	Tekever	Portugal
B-HUNTER	Aerial	Israeli Aerospace Industries	Belgium
Barracuda	Aerial	Airbus SE	Germany, Spain
Double Eagle SAROV	Underwater	Saab	Canada, Denmark, Poland
Gavia	Underwater	Teledyne	Denmark, Iceland, Poland, Portugal, UK, US
Harop	Aerial	Israeli Aerospace Industries	Germany
HUGIN	Underwater	Kongsberg	Netherlands
Husky	Ground	DCD Group	Latvia
Iver	Underwater	L3 OceanServer	Canada, Portugal, US
KARGU	Aerial	STM	Turkey
LUNA	Aerial	EMT Ingenieur	Germany
Manta	Underwater	NavyX	UK
MAST-9	Surface	L3Harris	UK
MAST-13	Surface	L3Harris	UK
Mission Master	Ground	Rheinmetall	Netherlands
MQ-9 Reaper	Aerial	General Atomics	US
Nerva	Ground	Nexter Robotics	France
nEUROn	Aerial	Dassault	France, Greece, Italy, Spain
Perun	Ground	Polish Armament Group	Poland
Puma 3	Aerial	AeroVironment	Czech Republic, Denmark, Estonia, Germany, Latvia, UK
REMUS 100	Underwater	Kongsberg	Belgium, Canada, Croatia, Netherlands, Norway, UK
RQ-4 Global Hawk	Aerial	Northrop Grumman	Estonia
RQ-11 RAVEN	Aerial	AeroVironment	Bulgaria, Czech Republic, Denmark, Estonia, Hungary, Italy, Netherlands, North Macedonia, Romania, Spain, UK, US
SABUVIS II	Underwater	European Defence Agency	Germany, Poland, US

ScanEagle	Aerial	Boeing	Canada, Czech Republic, Italy, Netherlands,
			Poland, Spain, UK, US
SeaCon	Underwater	Portuguese Navy	Portugal
SeaHunter	Surface	DARPA, Leidos	US
Skeldar V-200	Underwater	Saab	Belgium, Canada, Germany, Netherlands
Skylark I-LEX	Aerial	Elbit Systems	Czech Republic, France
SWORDFISH	Surface	Porto Harbour Authority,	Portugal
		Porto University, Porto Polytechnic, CIMAR	
Taranis	Aerial	BAE Systems	UK
TB2	Aerial	Bayraktar	Turkey
THeMIS	Ground	Milrem	Estonia, Latvia, Netherlands, Norway, UK, US
TOGAN	Aerial	STM	Turkey
VIKING 6x6	Ground	HORIBA MIRA	UK
WARMATE	Aerial	WB Group	Poland
Watchkeeper	Aerial	Elbit Systems, Thales UK	UK

Figure 3: Air and Missile Defence Systems, Autonomous Missiles, and AI-Enabled Aircraft

Program	Type	Developer	NATO Countries
ADATS	AMD	Oerlikon	Canada
Aegis	AMD	Lockheed Martin	Norway, Spain, US
AMRAAM	AMD	Raytheon	Bulgaria, Denmark, Hungary, Romania
AWISS	AMD	Diehl	Germany
Brimstone	Missile	MBDA	UK
C-DAEM	Munition	US Army	US
DARDO	AMD	Leonardo	Italy
F-35	Next-Generation Aircraft	Lockheed Martin	Belgium, Canada, Denmark, Italy, Netherlands, Norway, Poland, UK, US
Future Combat Air System	Next-Generation Aircraft	Airbus, Thales Group, Indra Sistemas and Dassault Aviation	France, Germany, Spain
Goalkeeper	AMD	Thales	Netherlands, Portugal
Harpoon Block II	Missile	Boeing	Belgium, Canada, Denmark, Germany, Greece, Netherlands, Poland, Portugal, Spain, Turkey
Joint Strike Missile	Missile	Kongsberg	Norway
MANTIS	AMD	Rheinmetall	Germany
Mistral 2	Missile	MBDA	Estonia, Hungary
MU90 IMPACT	Torpedo	Leonardo	Denmark, France, Germany, Italy, Poland
NASAM	AMD	Kongsberg	Lithuania
Naval Strike Missile	Missile	Kongsberg	Norway, Poland
Patriot	AMD	Raytheon	Germany, Greece, Netherlands, Poland, Romania, Spain, US
Phalanx	AMD	Raytheon	Portugal, UK, US
PULAT	AMD	ASELAN	Turkey
SAMP/T	AMD	Eurosam	France, Italy, US
SeaRAM	Missile	Raytheon	Germany, Greece
SPYDER	AMD	Rafael	Czech Republic
Tempest	Next-Generation Aircraft	BAE Systems	Italy, UK
TF-X	Next-Generation Aircraft	Turkish Aerospace Industries	Turkey

Figure 4: Data Analytics

Programme	Type	Developer	Countries
ARCHANGE	Signals intelligence analysis	Thales, Dassault Aviation	France
Automatic Imaging Target Acquisition	Target acquisition	MBDA	France
BlueScan	Anti-submarine warfare	Thales	France, Spain
LIMS IV	Logistics and mission support	US Air Force	US
Project Maven	Image analysis	US Department of Defense	US
TALIOS	Image and sensor analysis	Thales	France

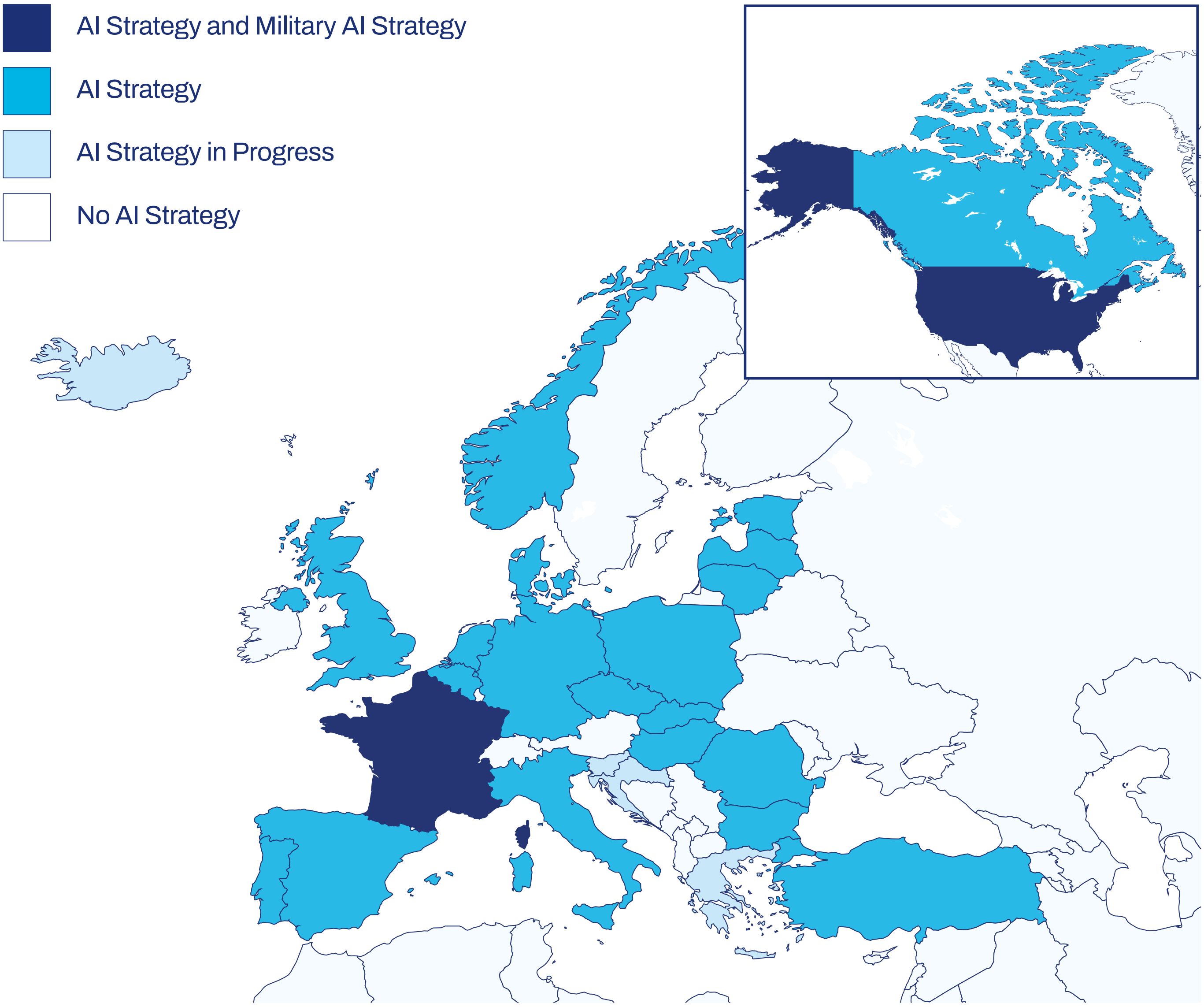
Figure 5: Logistics and Personnel Management

Programme	Type	Developer	Countries
Boatswain's Mate	Voice assistant	IBM	Canada
F4 Rafale Predictive Maintenance	Predictive maintenance	Thales	France
Mixed Reality Remote Assistant Support System	Augmented reality for ship maintenance	Kognitiv Spark	Canada
Project Salus	Supply chain shortage prediction	JAIC	US
Soprene Project	Predictive maintenance	Indra Sistemas	Spain
SWIM	Air traffic control		Germany

Figure 6: Other

Programme	Type	Developer	NATO Countries
CRAI	Communications and radar	European Defence Agency	Germany, Netherlands, Poland
Kalætron Attack	Electronic warfare	Hensoldt	Germany
SWORD	Simulation	MASA Group	Belgium, France, Spain

Figure 7: AI Strategies by Country, Map



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