Chapter 3

Emerging and Innovative Military Technologies in the EU Member States: Background and Issues

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Abstract

This chapter explores the evolving landscape of military technologies in the European Union (EU) the member states, covering its background, trends, and challenges. Rapid technological advancements have shaped military capabilities, requiring a comprehensive understanding by policymakers, defence analysts, and scholars. This historical overview emphasises the collaborative efforts and the impact of geopolitical shifts on defence strategies. The chapter examines emerging technologies such as artificial intelligence (AI), autonomous systems, cyber capabilities, and space-based innovations, illustrating their integration into military operations through case studies. Ethical, legal, and security issues are analysed, including consideration of autonomous weapons, cyber warfare legal frameworks, and proliferation risks. The chapter also examines standardisation challenges across the EU, and also rivalry between the U.S., China, and Russia. The impacts on the EU's power balance and global security, technological asymmetry, and cooperative measures are also discussed. The evolving military doctrines in the EU, influenced by technological advancements, are explored. The chapter concludes with a forward-looking perspective, offering policy recommendations for responsible innovation, collaborative research, and addressing the challenges inherent in the emerging technologies. Understanding these aspects is crucial to navigate the intricate military technology landscape and ensure a secure future for the European Union.

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1. Introduction

Gaining an advantage over the opponent, both on the conventional battlefield, as well as in cyberspace or outer space will depend on capabilities of operational and military technology, including those using the latest technological advancements. Technological progress influences the expansion of military equipment capabilities, and breakthrough technologies. Emerging and disruptive technologies (EDTs)[1] provide potential opportunities to rapidly improve critical parameters and accelerate the process of achieving an advantage over a possible opponent. The use of EDTs in the area of security and defence will have a positive impact on operational capabilities and shape the future battlefield. Hence, the active involvement of European countries in activities aimed at developing and implementing EDTs through national programmes and participation is allied and international partnership initiatives. New ways and means of conducting military operations appear, as well as new, previously unknown, and unidentified threats for which countermeasures must be found. Experience from the conflict in Ukraine is particularly valuable in this context, e.g. in terms of reconnaissance capabilities (acquisition, processing and use of information), command (automated command systems), air defence, and the use of anti-tank means (including the use of unmanned aerial vehicles [UAVs]), as well as the ability to provide logistic support and secure the state's critical infrastructure.

In the rapidly changing international landscape, military technologies are crucial for enhancing countries' defence potential, with European Union (EU) Member States leading the adaptation to new challenges. New technologies, including artificial intelligence (AI), cybersecurity, robotics, and modern communication systems, are pivotal for strengthening defence capabilities and offering innovative solutions for enhancing operational efficiency and effectiveness. This chapter examines the impact of these modern technologies on the defence systems of European countries, examining both the challenges and benefits of their implementation. These technologies not only alter the nature of warfare, but also shape the defence strategies of

1 NATO Advisory Group on Emerging and Disruptive Technologieswas established following a decision by the Heads of State and Government during a meeting in London in December 2019. The group's purpose is to advise NATO on new breakthrough technologies and their strategic implications. Membership is planned for two years, with the potential for a one-year extension. The group includes representatives from Bulgaria, Canada, Denmark, Estonia, France, Spain, Germany, Norway, the U.S., the United Kingdom, and Italy.

states.[2] Understanding the dynamics of these changes is extremely important in the context of the EU, which strives to build a common security and defence policy.[3]

This chapter focuses on the key issues related to emerging military technologies in EU Member States. The technological and political aspects that shape these processes are analysed. Moreover, the author attempts to identify the challenges and benefits related to the adaptation of new technologies in the defence field.

The first part of the chapter provides a brief historical context on the current situation of the EU Member States in the field of military technologies followed by an analysis of the key technologies that constitute the foundation of modern defence capabilities. In the next stage, the political issues involved on the integration of these technologies into the EU's common security and defence policies are discussed.

Finally, the prospects and challenges of emerging military technologies for EU Member States are discussed. This chapter aims to identify important issues and indicate possible directions for development and cooperation in the field of modern military technologies within the EU's defence community.

2. Developing military technologies in the EU

Before examining the latest defense system developments, it is valuable, it is valuable to briefly consider the historical context. Europe, a region marked by centuries of conflict, has continually adapted its defence strategies to evolving political environments and technologies.[4] Traditional defence methods, such as fortification and conventional armies, are evolving into more advanced solutions. The history of defence innovation and technology in Europe has been intertwined with centuries of dynamic military development. European countries have been instrumental in shaping the defence landscape, from medieval fortifications to contemporary cyber systems.[5] The history of European defence technology can be traced back to medieval castles and defensive walls, where innovative systems such as fortresses, defence towers, and underground tunnels were employed to secure strategic areas. In the 19th century, the Industrial Revolution significantly influenced military technology by introducing inventions such as the steam engine, steel, and mass production, leading to the creation of machine guns and artillery. World War I brought a new wave of innovations, including tanks, combat aircraft, and chemical weapons, revolutionising

2 Jonson, 2019, pp. 147–169.

3 The common security and defence policy (CSDP) is an integral part of the EU's common foreign and security policy (CFSP). The role of the European Parliament in the CFSP and the CSDP is defined in Title V, Chapter 2, Section 1 (Common provisions) and Article 36, and the funding arrangements for both policies are set out in Article 41.

4 Bickerton et al., 2022, pp. 173–182.

5 Csernatoni, 2021.

war strategies and emphasising the role of scientific research in the military. During World War II, the development of radar emerged as a key technological achievement.[6] Radar systems have enabled the effective detection of enemy planes and ships, which has been decisive for the course of many battles.[7] During the Cold War, the arms race between the Eastern and Western Blocs spurred innovation in spy satellites, ballistic missiles, and missile defence systems. In response to contemporary threats such as cyberattacks, European nations are prioritising advanced cyber and information security systems to safeguard critical infrastructure. With the increasing digitisation of European societies, cybersecurity has gained prominence in the context of defence. As cyber threats advance, European countries are actively seeking innovative solutions for their detection, response, and prevention. As cyber threats advance, European countries are actively seeking innovative solutions for their detection, response, and prevention.[8]

The ongoing history of defence innovation in Europe reflects a persistent pursuit of security excellence, adapting to scientific progress and geopolitical shifts. In the current global security environment, international cooperation is crucial for effective defence operations. European countries are increasingly collaborating to develop new defence technologies and navigate the challenges associated with such cooperation.

In recent years, the EU has actively engaged in initiatives to develop new military technologies. The landscape of military technology is dynamic, with ongoing and long-term developments. The key aspects related to the EU's involvement in this endeavour are as follows:

- **European Defence Fund**: The EU instituted the European Defence Fund to facilitate collaborative defence research and the development of capabilities among its Member States. The fund promotes cooperation in cutting-edge military technologies, encompassing areas such as AI, cyber capabilities, and advanced materials.[9]
- **Permanent Structured Cooperation (PESCO)**: PESCO provides a framework for EU Member States to strengthen their defence capabilities and collaborate in joint projects. This enables countries to pool resources and share the costs

6 Duignan and Leong, 2023.

7 McMahon, 2021, pp. 76–85.

8 The Commission and the High Representative of the Union for Foreign Affairs and Security Policy presented a new EU cybersecurity strategy on 16th December 2020. As a key component of *Shaping Europe's Digital Future*, the *Recovery Plan for Europe* and the *EU Security Union Strategy*, the strategy will bolster Europe's collective resilience against cyber threats and help to ensure that all citizens and businesses can fully benefit from trustworthy and reliable services and digital tools.

9 *Regulation (EU) 2021/697 of the European Parliament and of the Council of 29 April 2021 establishing the European Defence Fund and repealing Regulation (EU) 2018/1092* (Text with EEA relevance), 2021.

of developing new military technologies across various areas including strategic transport and cyber defence.[10]

- **Defence Innovation Accelerator for the North Atlantic (DIANA)**: DIANA is an organisation established by NATO to find and accelerate dual-use innovation capacity across the Alliance. It provides companies with resources, networks, and guidance to develop deep technologies for solving critical defence and security challenges, from operating in denied environments to tackling threats to our collective resilience.[11]
- **Horizon Europe**: Horizon Europe, the EU's primary research and innovation programme, includes a dedicated pillar for security research that supports advancements in various security-related fields, including defence technologies. The programme promotes collaboration between EU Member States and industry partners to enhance their technological capabilities.[12]
- **Strategic Compass**: The EU is developing a Strategic Compass to guide its common security and defence policy, fostering a shared understanding among Member States regarding common security threats and the capabilities to address them, including the identification and development of emerging military technologies.[13]
- **Cybersecurity and Artificial Intelligence**: Given the increasing importance of cybersecurity and AI in modern defence capabilities, the EU is focusing on these areas. Efforts are underway to develop cybersecurity technologies and strategies as well as guidelines for the responsible development and use of AI in defence.[14]
- **Collaboration with Industry**: The EU underscores collaboration between defence industries and Member States to foster the development of innovative military technologies. Encouraging public-private partnerships is a key approach to leveraging the expertise of both sectors.[15]
- Geopolitical shifts, technological progress, and policy priorities shape the direction and scope of these initiatives. Modern military technologies include AI, autonomous weapons, Big Data, space and quantum technologies, hypersonic missiles, new methods of destruction, drones, stealth technologies, lasers, and electronic weapons. How these innovations impact the combat

10 *Council Decision (CFSP) 2017/2315 of 11 December 2017 establishing permanent structured cooperation (PESCO) and determining the list of participating Member States*, 2017.

11 Allied Leaders agreed to launch the Defence Innovation Accelerator for the North Atlantic (DIANA) at the 2021 NATO Summit in Brussels, as part of the NATO 2030 agenda, and to establish a multinational venture capital fund to support innovation throughout the Alliance.

12 The Horizon Europe regulation, proposed by the Commission in June 2018, establishes the EU framework programme for research and innovation for the years 2021–2027. It lays down the objectives, the budget, the forms of EU funding and the rules for providing such funding in the field of research and innovation.

13 Document 7371/22, on 24th March 2022, European Union.

14 European Commission, 2021.

15 European Commission, 2022.

capabilities of European armies, and the potential threats associated with their use, are critical considerations.

2.1. Artificial Intelligence

AI has become an integral part of our everyday life, although for many people it is still a concept that is difficult to define. In recent years, AI has revolutionised our lives by reshaping business operations and communication. Beyond robots and autonomous vehicles, AI replicates and enhances human capabilities in learning, analysis, language comprehension, and pattern recognition. Despite some concerns, AI significantly impacts society. This study examines the advantages and risks of AI by examining its seamless integration into daily life. In defence, AI raises ethical and security concerns. Current efforts are focused on AI in cyberspace to analyse and counteract potential attacks. AI combined with VR or AR is poised to enhance military training cost-effectively. Integrating AI into C4ISR systems results in changes, provides secure information for soldiers and commanders, supports threat assessment, and optimises resource utilisation. AI plays a crucial role in electronic warfare by rapidly analysing the electromagnetic environment, facilitating effective countermeasures against attacks, and optimising military radio-frequency management.

Managing the expanding volume of data, particularly with advancing sensor technologies, poses a challenge. Creating a coherent operational picture in multi-domain allied operations, has become increasingly difficult. Advanced command support systems that use AI algorithms will play a crucial role in establishing a Common Operational Picture at higher command levels.

Building trust in artificial intelligence systems requires the use of proven reliable algorithms that operate deliberately and predictably. Another crucial aspect is having extensive databases of reliable and diverse data for AI training. Meeting these requirements is essential for the development of safe and trustworthy systems.

2.2. Autonomy and Autonomisation

Autonomy is an area of breakthrough technology that includes solutions that enable the creation of systems capable of making decisions independently, as well as physical tools to implement these decisions.[16] Considering the complexity of solutions implementing these functions, a more precise formulation is used in the form of autonomous systems (ASs)[17] and when we indicate their connection with physical effectors–robotics and autonomous systems (RAS).[18]

16 Merriam-Webster Dictionary, no date.

17 "Autonomous Systems" mean systems that incorporate artificial intelligence (AI) into the management and control of complex systems. Autonomous systems are operated independently of other management and control systems, though may include human operators (i.e., crew) as part of the operation.

18 Chakraborty, 2021.

Autonomy in decision – making mechanisms and physical tools can mirror the operations and structures of living organisms. This approach, inspired by nature, enables tools to either support or replace humans in the execution of tasks which (i) require maintaining a high level of concentration on the work performed for a long time without the negative effects of fatigue or distraction, (ii) are dangerous to life or health, and (iii) require the development of decisions based on a multi-aspect assessment of the situation using data from multispectral sensor systems and accumulated knowledge resources.

Automation and, in the subsequent stages of development, autonomy of military equipment will take place in various areas, such as reconnaissance, logistics, security, survival of troops, and ultimately, destruction.

Military automation, progressing to autonomy, encompasses reconnaissance, logistics, troop security, and combat. Autonomous reconnaissance platforms excel in information acquisition, conduct missions under diverse conditions, enhance situational awareness, and minimise the risks associated with hidden movements. Autonomous logistics platforms streamline supply delivery in various environments, thereby enhancing subunit mobility and reducing personnel reliance. In troop protection, autonomous recovery platforms swiftly retrieve injured individuals and minimise the exposure of medical personnel to combat. Autonomous combat systems, which have the potential to replace soldiers, are realistically envisioned in human–machine teaching, with human control over crucial decisions. Legal provisions for autonomous combat machines are lacking and pose significant regulatory challenges.

2.3. Analysis, processing and management of large data sets – Big Data

The advantages of the modern battlefield hinges on superior information derived from extensive knowledge of the operational situation and prompt access to essential data. A diverse array of information sources necessitates tools for effective analysis, enabling the identification of relationships and the comparison of anomalies with established patterns in vast datasets. This technological realm is known as Big Data.[19] This concept involves widely distributed databases with synchronisation mechanisms to ensure security, consistency, and data nonrepudiation (e.g. blockchain). It also encompasses robust analytical functions for extracting and presenting the results in the desired accessible format.

As the IoT, advanced reconnaissance, electronic warfare, automated cyber defence, and AI-based command support grow, the analysis of large datasets becomes crucial. Efficient analytical tools in decision-making centres offer a significant advantage on modern battlefields. Cloud and edge computing reduce information exchange latency and installation costs, particularly in hardware, thereby addressing the limitations in data processing for C4ISR systems in tactical environments

19 European Parliament, 2021.

2.4. Quantum technologies

The area of quantum technologies should be considered groundbreaking and can make a significant contribution to the development of defence technologies in the long term. Areas particularly susceptible to the impact of quantum technologies include command support systems at all levels and cybersecurity, communications, and radar technologies.[20]

Quantum computers, with their unique operation, have significantly enhanced computational capabilities compared with conventional machines. Unlike typical PCs, they are tailored for specific tasks, leveraging their efficiency and speed to solve complex mathematical and physical problems. The main challenge in building quantum computers is the accurate extraction of discrete values from the Qbit spectrum[21] states and their instability. Difficulties increase as the number of words for which the calculations are performed increases.

The rise of quantum computers poses a significant threat to existing encryption algorithms, prompting the urgent need for post-quantum safe cryptography solutions. Quantum Key Distribution has emerged as a potential solution for securing key distributions in ICT networks.

Quantum technologies, particularly high-sensitivity sensors and quantum gravimeters, offer significant advancements in submarine navigation. The impact of quantum computing has extended to pattern recognition and analysis, revolutionising reconnaissance techniques in sonar, radio, radar, and satellite technologies. This shift may render the stealth technology less effective for detection.

In defence applications, quantum computers are used to simulate physical and chemical phenomena, aiding in the study of materials for weapons, vehicle armour, aviation, and counteracting CBRN threats. Quantum physics also holds promise for the development of secure communication channels that are resistant to interference and eavesdropping.

Although quantum technologies promise transformative effects on defence capabilities, achieving these outcomes requires long-term and expensive interdisciplinary research. This includes advancements in vacuum, laser, temperature, materials, IT, and electronic circuit manufacturing technologies.

2.5. Space technologies

Drawing on advancements in other fields, space technologies form a distinct research domain because of the unique and often extreme conditions of space and orbital placement. The components of space systems must withstand overloads, shocks, wide temperature variations, and prolonged exposure to cosmic radiation

20 Cornet, Hua and Honggang, 2020, pp. 5–9.

21 "Bit" – a unit of informator in QT, it does not accept discrete values 0 and 1, which are currently used in classical computers.

while maintaining a low electricity demand. Additionally, they require resilience to natural and intentional disruptions, along with effective self-control, monitoring, and removal mechanisms.[22]

Space, which is acknowledged as the fifth operational domain by the Alliance, presents an opportunity to gain an advantage over potential adversaries. Sensors on space platforms, including radar, electro-optical, and thermal sensors, acquire image data that are crucial for reconnaissance to locate and identify enemy activities, infrastructure, and equipment. Earth satellite observation systems and meteorological analyses play vital roles. Precision strikes are essential in armed conflicts, emphasising the importance of developing interference-resistant satellite navigation and time-synchronisation systems.

Satellites supporting global telecommunications maintain crucial communication links during military operations worldwide, thereby contributing to operational awareness. However, dedicated transmission security mechanisms are required for preventing adversary control. Future challenges in space technology applications may involve finding solutions in areas such as quantum technologies for fast and secure communication, Big Data for efficient information searches, AI for satellite platform autonomisation, and advancements in materials and manufacturing technologies.

Satellites may evolve beyond reconnaissance and communication to perform combat missions using kinetic and non-kinetic means, including missile weapons, lasers, and electromagnetic weapons. Countermeasures must be developed to address potential threats to this evolving landscape.

2.6. Hypersonic missile systems

Hypersonic weapons represent the culmination of advanced and expensive technologies, with major military powers approaching their final implementation phase. The global pursuit of supremacy and capacity for pre-emptive strikes, including nuclear strikes, have driven significant financial and technological investments. The primary goal is to establish a deterrent effect that allows one to effectively penetrate enemy air defence by reducing travel times to distant strategic targets. Hypersonic missile systems, primarily within the reach of the world powers, focus on offensive strategic capabilities. Scientific efforts should prioritise measures for detecting, tracking, and neutralising potential threats posed by adversaries using such weapons.[23]

The development and production of hypersonic weapons involve addressing numerous theoretical and technical challenges, including high-performance rocket engines, advanced rocket fuels, hypersonic aerodynamics, engineering heat-resistant materials, guidance theory, motion sensors, automatic pilots, semiconductor electronics, executive mechanisms, radio systems, radio igniters, and warheads. Creating

22 Pahwa, 2023.
23 Seldin, 2022.

an aerodynamic system for a hypersonic rocket body, along with control systems, is a significant interdisciplinary scientific and engineering challenge accompanied by substantial financial commitments, including investment costs for constructing a hypersonic wind tunnel.

2.7. Biotechnologies and technologies to enhance the capabilities of the human body

Biotechnology harnesses living organisms or their components for various functions, such as detecting CBRN threats, influencing organisms, and modifying human bodies to develop or enhance desired features. This may involve operations on human genetic material.[24]

Human Enhancement Technologies aim to improve human abilities in various areas. Strengthening the perception of the environment, also in relation to the tactical situation, is possible by supporting people with devices and interfaces that provide information necessary to perform specific tasks in an easily digestible form. An example of such a solution may be augmented reality systems that supplement the image seen with the naked eye or via a camera with computer-generated objects.[25]

The enhancement of human performance, including physical strength, requires the use of exosuits and exoskeletons. Long-term efforts include biomedical interventions for musculoskeletal augmentation, legal regulations, and moral concerns. The creation of mixed human–machine teams necessitate the development of effective interfaces for controlling such equipment. Human improvement aims to positively increase physiological, cognitive, and social functions by involving various technologies, such as drugs, hormones, implants, and genetic engineering.

2.8. Material and manufacturing technologies

Multidisciplinary research in chemistry, physics, and technical sciences is a source of innovative materials with new or improved properties, the use of which may contribute to the development of military technology and increase the potential of the armed forces. One of the necessary conditions for meeting this challenge is the development of new energy sources and construction materials with high strength and durability.

Advanced construction materials exhibit superior properties such as enhanced mechanical strength, reduced weight, and improved thermal or electrical conductivity. Technologies, such as ceramics, electronic materials, composites, polymers, and biomaterials, have facilitated their production. Intelligent materials capable of intentional property changes combine the sensor, processor, and activator functions. Multifunctional materials, particularly composites, play a vital role in military

24 *Science & Tech*, no date.
25 Pariseau-Legault, Holmes and Murray, 2019.

equipment by providing high strength and stiffness, condition diagnosis, self-repair capabilities, and electromagnetic wave suppression.

Additive technology, including 3D printing, allows the cost-effective and rapid production of monolithic objects and reduces assembly complexity and material usage. This is advantageous in terms of weight reduction and onsite spare-part production for military applications. Joining materials involve various techniques such as welding, lasers, and hybrid methods. Advanced connection methods, such as rivet nuts, are being developed for the efficient design and repair of composite structures using military technology.

Surface modification technologies enhance the hardness, wear resistance, and thermal resistance of construction materials. The application of composite nanolayers to fabrics improves soldier protection and comfort by providing thermal, electromagnetic, and mechanical barriers through optimised coatings.

2.9. Drive systems technologies

Advancements in military technology and the introduction of new types of SPW have necessitated the development of more efficient propulsion, fuel, and power systems with reduced exhaust emissions and alternative operating methods. These developments are closely linked to modern material technologies. Drive systems are becoming increasingly complex and require component miniaturisation, sophisticated measurement devices, and sensors for condition analyses. Modifications to modern engines necessitate the use of appropriate fuels to meet specified standards for both conventional and alternative fuels. These alternative fuels include materials and substances that can replace traditional fuels, nuclear fuels, and artificial radioisotope fuels produced in nuclear reactors.[26]

Advanced fuels offer a pathway to reduce the dependence on conventional hydrocarbon fuels and enhance energy security in European countries and their armed forces. These alternative fuels are expected to possess favourable energy properties, lower the emissions of harmful compounds, and contribute to mitigating the effects of global warming.

2.10. Power sources and energy storage technologies

Currently, most military equipment and components require electricity. To meet the growing demand for electricity and become independent of power sources using fossil fuels, it is necessary to use alternative energy sources and conduct research on their new types.[27]

Converting solar energy into electricity is a priority given the vast potential of solar radiation. Photovoltaic (PV) cells, which are also known as solar cells, are

26 See: ISO, 2021.
27 Wahab, 2014.

crucial for this photovoltaic conversion. Enhancing the efficiency and developing durable structures suitable for military applications, such as foldable mats, are key goals. In military equipment, electronic systems require efficient power sources, and chemical power sources play a vital role in maximising energy accumulation with minimal weight and dimensions to meet the demands of continuous device miniaturisation. The development of new and highly efficient energy storage methods can significantly increase the potential of military technology, which is sometimes used under extreme conditions.[28] They can be used as emergency power sources to maintain the operation of entire systems, helping save energy in vehicles, for example, by allowing the engine to be turned off after stopping and then quickly starting it again. Their use in military equipment may have a positive impact on the start-up of engines at very low ambient temperatures, as well as on the launch of rotating tower mechanisms, other combat systems, and power supply support systems for engineering robots.

2.11. Sensors

Sensors and sensory systems are essential data sources for achieving situational awareness and for supporting operational activities. Reconnaissance tasks rely on imaging devices (optical, multi- and hyperspectral, and laser systems), efficient radars (potentially longer-term quantum radars), and sensors for the electromagnetic environment (analysing the electromagnetic spectrum of the operational space). These devices are applicable to various reconnaissance platforms such as manned, unmanned, autonomous, and military infrastructure facilities. They offer space utilities through satellite equipment and the ground for monitoring potential enemy activities.[29]

Sensory techniques are used in navigation, military protection, survival, and medicine. In navigation, efforts have focused on enhancing the accuracy of positioning and time synchronisation systems across all military platforms, which are crucial for aviation and precision weapons. Quantum gravimeters utilising quantum phenomena are promising for vessels, both surface and underwater, navigating under conditions with limited GNSS signals.

Advancements in destruction systems, including target designation and effective effectors, require sensors for swift threat detection and classification. These, combined with responsive active protection systems, are crucial for increasing the probability of the survival of crew members and supporting equipment on the battlefield.

Sensor technologies for military protection and survival encompass the detection and qualitative assessment of chemical (especially fourth-generation), biological, and

28 *Storage Technology Definitions*, no date.

29 Miklush, no date: ‘The sensory system is responsible for detecting and processing sensory information from the environment and converting it into electrical signals that can be interpreted by the brain. The sensory system has two parts: the general sense and the special sense’.

radiological contaminants. These technologies also focus on minimising or altering signatures (magnetic, acoustic, and thermal). Applications range from individual soldier equipment to portable/transportable devices for military units, specialised units, chemical services, and national defence against weapons of mass destruction. Additionally, these sensor technologies detect and identify chemical, biological, and radioactive contamination, adapting to the required level of identification of weapons of Mass Destruction (WMD) factors,[30] various analytical techniques are used. In modern battlefields, the focus is on detecting and identifying WMD agents under field conditions. These include portable contamination detectors, onboard equipment for unmanned aerial vehicles, wearable detectors for individual soldiers, and Wireless Sensor Networks for area monitoring. The development of signature control technologies for land, air, and sea platforms, including unmanned platforms, can reshape future battlefields. Innovations in materials, IT systems, and sensors will enhance the real-time identification, imaging, and control of platform signatures, improving situational awareness, mission effectiveness, and platform survivability.

Medical sensors also play an important role in this context, and biosensors based on biologically active particles demonstrate promise. They measure and evaluate human biological processes, providing insights into a soldier's psychophysical condition, efficiency, and stress levels, which are crucial for determining their ability to perform assigned tasks.

2.12. New destruction systems

Destruction systems alter target characteristics and impacts by employing both kinetic and non-kinetic agents. They provide a versatile spectrum of applications against various threats ranging from temporary disruptions to complete destruction.[31]

Research and development should focus on new means of destruction, including artillery and missile systems, for land, air, sea, and space domains (considering missile systems for space). Improvements should aim to enhance precision and impact force, involving advancements in pyrotechnic materials, initiating devices, and missile propulsion systems. Targeting, identifying, and tracking systems for fast-moving targets are crucial for increased effectiveness.

Directed energy systems such as lasers and electromagnetic weapons are essential for countering emerging threats such as unmanned aerial platforms. In addition, efforts should be made to address systems that disrupt communication and allow the impersonation of an authorised user to take control of the opponent's platform. The development of systems that protect military equipment against enemy influences is critical.

30 UN General Assembly, 1977.
31 Varlamov, Rimshin and Tverskoi, 2018, pp. 808–811.

2.13. Information and telecommunications technologies

The development of information and telecommunications technologies is closely related to the need to achieve an information advantage.[32] The extraction of crucial information relies on analytical tools including Big Data mechanisms and AI algorithms. Ensuring availability at a scheduled time is essential. Although radio signals remain the primary means of data transmission in military tactical systems, cognitive radio and 5G technology offer optimised conditions for cellular communications.

Whether cables, fibre optics, radio, or hybrid communication are used, security is paramount, encompassing confidentiality, non-repudiation, and data integrity. In the cyberspace domain, autonomous cyber response capabilities are crucial for maintaining the availability of command, communication, and weapons support systems, and for ensuring data integrity on the battlefield. Technologically advanced adversaries pose a significant threat to massive cyberattacks targeting military systems and networks. Isolated systems may have limited remote-management capabilities, necessitating autonomous cyber responses and self-configuration abilities.

Developments in quantum technologies have introduced new threats and countermeasures in the information and cyberspace domains. Adapting to global trends in quantum technology is vital for European countries and their armed forces.

2.14. Simulation systems

Simulation systems analyse real objects through digital models, examining the relationships and impacts of decisions on system functioning. Virtual and augmented reality technologies enhance human interaction with digital objects, increase cognitive value, improve effectiveness, reduce costs, and shorten the duration of training projects for the technical maintenance of military equipment.[33]

Efficient algorithms for modelling scenarios and the operational environment are essential for effective military operations management, offering theoretically unlimited possibilities for various actions. An additional benefit is the opportunity for earlier training and preparation of commanders and troops in real operational scenarios.

The idea of digital twins plays a pivotal role in creating new hardware solutions. This study addresses three aspects. First, it provides support for technical analysis (examination of the condition of a real object to improve the planning of service, repair, and maintenance activities). Second, it ensures a digital reflection of the life cycle of a physical object (analysis of its long-term behaviour, prediction of actions/behaviours, ensuring continuity of information at various stages of the life cycle, and management of the life cycle of devices). Third, it supports decision-making by performing engineering and statistical analyses to optimise system behaviour at the design stage, predict development directions, and improve future product performance or parameters.

32 Rouse, no date.
33 Leonelli, 2021, pp. 111–123.

Digital Twin technology enhances the efficient design of new military equipment, expedites production, and minimises previously unknown “childhood” issues. Operational processes benefit from improved efficiency, reducing the downtime caused by equipment failures through optimal scheduling of repairs or technical services. Planning to enhance military equipment can be incorporated into the design stage.

2.15. Medical protection of the battlefield and countermeasures

Medical protection on the battlefield and the organisation of the functioning of the military health service primarily focus on technologies that help overcome challenges related to evacuation and transport, including unmanned transport of injured people and medical supplies, and in conditions of contamination and infection, while maintaining isolation from factors (pathogens) that threaten the health or life of crews and medical staff.[34] In the medical domain, technologies for locating wounded individuals on the battlefield, as well as the automation and robotisation of medical procedures, are of interest. This includes autonomous life and health-support systems. Research on medical protection involves technologies for individual and collective protection against CBRN agents; decontamination of people, animals, and military equipment; and advanced disinfectants for field conditions.

The development of medical countermeasures (MCM), which cover the diagnosis, prevention, and treatment of the consequences of exposure to CBRN agents, is crucial. Improving the technology for diagnosis and treatment remains an ongoing need.

Efficient military health service operations rely on the development of medical information management support systems. These systems track the flow of injured individuals, automate medical documentation processes (e.g. QR coding and chip cards), and utilise AI for diagnostics, decision support, and data analysis. Therefore, research on storage systems for medical supplies and blood products, and additive printing technologies in medicine, including portable 3D printers for medical materials, is necessary.

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3. The new selected emerging military technologies in the United States, China and Russia

The U.S. military, comprising the army, navy, and air force, has overcome legacy features through revolutionary innovations in key technological areas. Despite the entrenched sectors, the Defense Advanced Research Projects Agency (DARPA) serves as a unique innovation organisation that addresses military challenges through high-risk, high-reward projects. DARPA’s contributions to revolutions in military

34 Saracino, 2019.

affairs, such as precision strikes, stealth aircraft, and unmanned aerial vehicles, highlight its distinct operating characteristics. Officials from the Department of Defense, Congress, and Pentagon are increasingly focusing on developing emerging military technologies to maintain U.S. national security and technological superiority. Initiatives such as the Third Offset Strategy and entities such as the Defense Innovation Unit reflect efforts to exploit emerging technologies for military purposes.

The U.S. Congress and Pentagon officials are intensifying efforts to prioritise cutting-edge military technologies, recognising their critical role in national security. Historically, the U.S. military has relied on technological superiority, but rapid advancements and widespread technology dissemination have posed challenges to established norms. Former Secretary of Defense, Chuck Hagel, highlighted the threat to conventional military advantages. To counteract this, innovation must be fostered by collaborating with the private sector. Initiatives such as innovation hubs and research centres aim to shape the future of U.S. military prowess, ensuring adaptability and proactive influence on global security dynamics.[35] In recent years, the Department of Defense has launched initiatives to counter these technological challenges. The 2014 announcement of the Third Offset Strategy reflects a commitment to leverage emerging technologies for security and military purposes, including strategies, tactics, and operational concepts.[36]

In support of this strategy, the Department of Defense established organisations such as the Defense Innovation Unit and the Defense Wargaming Alignment Group. Aligned with the U.S. National Defense Strategy, these initiatives recognise the impact of rapid technological progress and evolving warfare on national security. This strategy emphasises the importance of cutting-edge technologies such as advanced computing, AI, hypersonic, and biotechnology in shaping future military capabilities. By proactively integrating these advancements, the U.S. aims to stay ahead in the dynamic landscape of modern warfare, address emerging threats, and maintain a strategic advantage in global security.[37] The U.S. leads in technology; however, China and Russia, recognised as strategic competitors, are rapidly advancing sophisticated military technologies. The integration and deployment of these technologies by foreign and domestic military forces have implications for Congressional considerations and global security.

Let us provide an overview of specific emerging military technologies in the United States, China, and Russia: AI, lethal autonomous weapons, hypersonic weapons, directed energy weapons, biotechnology, and quantum technology. This text explores key initiatives within international institutions designed to oversee and regulate the development of emerging technologies. It examines the potential consequences of advancements in military technology and provides an overview of

35 Hagel, 2014.
36 Work, 2014.
37 Department of Defense, 2018.

related concerns for the Congress. These issues may have far-reaching implications for Congressional authorisation, appropriation, oversight, and treaty negotiations.

3.1. Artificial Intelligence[38]

The U.S. government lacks an official definition of ((AI). Policymakers commonly use this term to describe computer systems that exhibit human-level cognition. AI can be categorised into narrow (specific) and general (wide-ranging) tasks. However, true AI systems with human-like cognition currently do not exist, and their realisation is uncertain.[39] Presently, the integration of narrow artificial intelligence is evident in various military applications employed by both the United States and its adversaries. These applications extend beyond intelligence, surveillance, reconnaissance,[40] logistics, cyber operations, command and control, and semi-autonomous and autonomous vehicles. These technologies aim to substitute for and enhance human operators and handle complex tasks. Artificial-intelligence-powered systems can react faster and manage vast data volumes, enabling strategic advantages such as swarming in combat. However, challenges have arisen, including algorithmic biases. Facial recognition programmes exhibit racial bias, emphasising the importance of diverse training data. Gender bias has also been observed in natural language processing programmes, which require careful development and mitigation strategies for AI.[41] Biases in AI used in military settings can lead to unintended harm, especially when lethal consequences are involved. The deployment of AI in lifelike digital forgeries, known as "deepfakes", presents risks, allowing adversaries to exploit this capability for information operations during grey zone conflicts.[42] Deepfake technology poses a threat to the U.S. and its allies, enabling the creation of fake news, the manipulation of public discourse, the erosion of trust, and potential blackmail attempts. Experts suggest that social media platforms should not only deploy detection tools, but also consider broader approaches, such as content authentication, requiring users to specify creation details or label-edited content.

However, some analysts caution against excessive regulation, citing the potential burdens on platforms and concerns regarding free speech. They argued that existing laws and public education efforts are sufficient to address malicious deepfake use.

United States

U.S. non-classified AI investments surged from $600 million in Fiscal Year 2016 to approximately $874 million in Fiscal Year 2022, with over 600 active AI projects

38 See: Sayler, 2020.
39 Bostrom, 2014.
40 Nishawn, 2020.
41 Barrett, 2018; Will, 2016.
42 Theohary, 2023.

overseen by the responsible division. The Department of Defense established a Joint Artificial Intelligence Center in accordance with the 2019 National Defense Authorization Act. This centre, endowed with acquisition authority under Section 808 of the Fiscal Year 2021 National Defense Authorization Act (PL 116-283), supervises AI projects that exceed $15 million.[43] The Joint Artificial Intelligence Center leads National Mission Initiatives in areas such as predictive maintenance, humanitarian aid, disaster relief, war fighter health, and business process transformation. Additionally, it manages the Joint Common Foundation, a secure cloud-based AI development and experimentation environment, for testing and deploying department-wide AI capabilities.[44]

The National Defense Authorisation Act for Fiscal Year 2019 mandates that the Department of Defense create a strategic roadmap for the development and deployment of AI. Guidelines on ethical, legal, and other policies governing the use of AI-enabled systems and technologies in operational scenarios are also required.[45] In support of this mandate, the Defense Innovation Board, an independent federal advisory committee for the Secretary of Defense, has drafted recommendations regarding the ethical use of AI.[46] In line with these suggestions, the Department of Defense embraced five ethical principles for AI, aligned with the recommendations of the Defense Innovation Board: responsibility, equitability, traceability, reliability, and governability. On 26 May 2021 Deputy Secretary of Defense Kathleen Hicks issued a memorandum offering guidance on the implementation of responsible artificial intelligence, in adherence to these ethical principles.[47] The Joint Artificial Intelligence Center is charged with developing and implementing a responsive artificial intelligence strategy, guidance, and policies.[48]

In conclusion, Section 1051 of the Fiscal Year 2019 National Defense Authorization Act established the National Security Commission on Artificial Intelligence. The Commission aimed to assess militarily significant AI technologies and provide recommendations to enhance U.S. competitiveness. The final report, presented to the Congress in March 2021, outlines recommendations across five key lines of effort: investing in development and research, applying AI to national security missions, recruiting and training AI talent, building and protecting United States technological advantages, and marshalling global AI cooperation.[49]

43 Public Law No. 115-232 (2018) Section 2, Division A, Title II, § 1051; and Public Law No. 116-283 (2021) Section 2, Division A, Title VIII, § 808.

44 Available at: https://www.ai.mil/jcf.html (Accessed: 28 February 2024).

45 Public Law No. 115-232 (2019) Section 2, Division A, Title II, § 238.

46 Defense Innovation Board, 2019.

47 Hicks, 2021.

48 Ibid.

49 National Security Commission on Artificial Intelligence, 2021.

China

China is widely recognised as the primary rival of the United States in the global AI market. China's 'Next Generation Artificial Intelligence Development Plan' from 2017 positions AI as a "strategic technology" and designates it as a pivotal focal point in the realm of international competition.[50] China has recently demonstrated significant progress in AI, particularly in language and facial recognition technologies. These advancements are intended for integration into the nation's domestic surveillance network with potential applications in countering espionage and enhancing military targeting capabilities. China is also actively involved in developing autonomous military vehicles for various operations, including swarm technologies, to overcome adversary missile defence interceptors. Open-source information indicates ongoing efforts to create a suite of AI tools for cyber operations.[51] China's oversight of its AI ecosystem contrasts with that of the United States. In China, there are minimal boundaries between the military, the central government, university research laboratories, and commercial enterprises. The National Intelligence Law of China mandates cooperation with the national intelligence, highlighting the interconnected relationships between different sectors and national intelligence efforts. Consequently, the Chinese government has a direct mechanism for steering military AI development priorities and accessing technologies originally developed for civilian applications.

Russia

Russian President Vladimir Putin emphasised that the individual or nation taking the lead in the field of AI will wield a significant influence on a global scale. Currently, Russia lags behind the United States and China in the development of AI. To bridge this gap, Russia has unveiled a national strategy outlining specific benchmarks for the next 5 and 10 years. These goals include enhancing AI expertise, refining educational programmes, expanding datasets, fortifying infrastructure, and refining legal and regulatory frameworks.[52]

Russia affirmed its commitment to persist in implementing its defence modernisation agenda in 2008. The initial plan aimed to incorporate robotics into 30% of the country's military equipment by the year 2025.[53]

The Russian military is actively exploring AI integration, particularly for semi-autonomous and autonomous military vehicles. Recent successes include the development of a combat module for unmanned ground vehicles, which enables autonomous target identification and engagement. Future plans involve expanding

50 China State Council, 2017, p. 2.
51 Kania, 2017, p. 27.
52 See: Office of the President of the Russian Federation, 2019.
53 Simonite, 2017.

autonomous systems with AI capabilities and extending efforts to unmanned aerial, naval, and undersea vehicles, with a specific focus on developing swarming capabilities.[54]

Implementing AI in Russia has the potential to reduce costs and manpower requirements, thereby allowing the deployment of more systems with fewer personnel. Russia is exploring AI applications in remote sensing and electronic warfare to disrupt adversaries' communication and navigation on the battlefield. AI is used extensively in domestic propaganda, surveillance, and information operations. However, achieving substantial progress in AI development may face challenges, as Russian academics rank 22nd globally in AI-related publications[55] and the Russian technology industry has yet to produce AI applications on par with those produced in the United States and China. However, other viewpoints suggest that these factors may be inconsequential. Some analysts argue that historically, Russia has not been at the forefront of Internet technology, yet it has successfully emerged as a significantly disruptive force in the realm of cyberspace.[56] Russia could leverage its expanding technological collaboration with China as a resource.[57]

3.2. Lethal Autonomous Weapon Systems (LAWS)[58]

Lethal autonomous weapon systems (LAWS), as characterised by the Department of Defense Directive, are weapon systems capable of independently identifying and engaging targets without manual human control, often described as "man out of the loop" or „full autonomy". This is distinct from human supervised ("human on the loop") autonomous weapon systems, where operators can monitor and intervene, and semi-autonomous (human in the loop") systems that engage targets selected by a human operator.[59] LAWS rely on computer algorithms and sensor suites to classify objects as hostile, make engagement decisions, and guide weapons to targets. While still in early development, these systems are expected to support military operations in environments with limited communication, thereby addressing operational challenges. Analysts suggest that LAWS can improve the precision in striking military objectives and minimise the risk of collateral damage or civilian casualties.[60]

Approximately 30 countries and 165 non-governmental organisations call for a pre-emptive ban on LAWS due to ethical concerns. Questions about accountability, doubts about adherence to the law of armed conflict's proportionality and distinction requirements, and operational risks are central to advocacy.

54 Bendett, 2017.
55 Konaev et al., 2021, p. 9.
56 Gregory, 2017.
57 Bendett and Kania, 2019, cited in Konaev et al., 2021.
58 See: Lucas, 2016.
59 Department of Defense, 2012.
60 U.S. Government, 2018.

LAWS pose risks, such as hacking vulnerabilities, manipulation of enemy behaviour, unforeseen environmental interactions, and software errors. Unlike automated systems, LAWS lack direct human intervention, increasing the potential for fratricide, civilian casualties, and other unintended consequences.

United States

The United States is not currently developing or deploying LAWS, and none are in its inventory. While there is no explicit prohibition, the Department of Defense Directive offers guidelines for the potential future development and deployment of LAWS, emphasising compliance with the laws of war, treaties, safety regulations, and rules of engagement.[61] This directive includes the requirement that LAWS be designed to „allow commanders and operators to exercise appropriate levels of human judgement over the use of force".[62] Effective decision-making regarding the use of force does not necessitate manual human „control" of the weapon system, contrary to common perception. Instead, it entails extensive human engagement in determining how, when, where, and why weapons will be deployed.

Changes in a system's operational status, particularly those driven by machine learning, demand comprehensive retesting and reassessment of safety and intended functionality. LAWS undergo a dual senior-level evaluation, which includes key figures such as the Under Secretary of Defense for Policy, the Chairman of the Joint Chiefs of Staff, and either the Under Secretary of Defense for Acquisition and Sustainment or the Under Secretary of Defense for Research and Engineering. This evaluation precedes the development and deployment, and a handbook is being developed to guide senior leaders.

China

As noted by Mark Esper, former United States Secretary of Defense, certain Chinese weapons producers, including Ziyan, publicly promoted their weapons by claiming autonomous capabilities in target selection and engagement.[63]

However, the validity of these claims remains unclear. However, it is crucial to note that China lacks explicit prohibitions on the development of LAWS, defining them based on at least five specific attributes:

Lethality entails an ample payload (charge) and the capability to effectively cause harm.

Autonomy refers to the absence of human intervention or control throughout the task execution process.

61 Department of Defense, 2012; Sayler, 2024a.
62 Department of Defense, 2012.
63 See: Tucker, 2019.

The inability to terminate implies that, once initiated, there is no method to halt the device.

The indiscriminate effect implies that the device will execute the task of killing and maiming regardless of the conditions, scenarios, and targets.

Evolution means that, through interaction with the environment, a device can learn autonomously and expand its functions and capabilities in a way that exceeds human expectations.[64]

Russia

Russia has put forth the following definition for LAWS: 'unmanned technical means, distinct from ordnance, designed to execute combat and support missions without operator involvement beyond deciding whether and how to deploy the system'.[65] Russia has recognised that LAWS could improve weapon precision on military targets, potentially reducing unintended strikes on civilians and non-military targets. Although Russia has not explicitly announced the development of such systems, reports suggest that Kalashnikov, a Russian weapons manufacturer, has created a combat module for ground vehicles with autonomous target identification and engagement capabilities.[66]

3.3. Hypersonic Weapons[67]

Several nations such as the United States, Russia, and China are actively advancing the development of hypersonic weapons capable of reaching speeds of at least Mach 5, which is five times the speed of sound. Hypersonic weapons can be broadly classified into two categories: Hypersonic glide vehicles propelled by a rocket upon launch and subsequently gliding towards their target, and hypersonic cruise missiles powered by high-speed engines throughout the flight period.

In contrast to ballistic missiles, hypersonic weapons avoid parabolic ballistic trajectories. They can dynamically manoeuvre toward their targets, making the defence challenging. Analysts differ regarding the strategic implications of hypersonic weapons. Some experts highlight two factors that could significantly influence strategic stability: the brief duration of the weapon's flight, which subsequently compresses the timeline for a response, and the unpredictable trajectory it follows, which could create ambiguity regarding the intended target of the weapon, thereby increasing the likelihood of miscalculation or unintended escalation in the event of a conflict.

64 United Nations, 2018, p. 1.
65 United Nations, 2019.
66 Mizokami, 2020.
67 See: Sayler, 2024b.

However, contrary opinions from some analysts suggest that the strategic impact of hypersonic weapons is limited. They argued that countries such as China and Russia, as competitors to the United States, already have the capacity to target the United States using intercontinental ballistic missiles. These missiles, particularly when launched in salvos, could potentially overpower the U.S. missile defence.[68] Moreover, these analysts contended that the traditional principles of deterrence still apply to hypersonic weapons. They assert, 'It is a significant stretch to envision any regime in the world being so suicidal as to contemplate, let alone execute, the threat or use of hypersonic weapons against the United States… the outcome would undoubtedly be dire'.[69]

United States

In the budget proposal for the Fiscal Year 2022, the Pentagon sought $3.8 billion for the development of hypersonic weapons and an additional $248 million for programmes focused on hypersonic defence.[70] The Department of Defense is actively advancing hypersonic weapons through the navy's conventional prompt-strike programme. This initiative seeks to provide the U.S. military with the capacity to target fortified or time-sensitive objectives using conventional warheads. Progress in hypersonic weapon development is underway through programmes led by the U.S. Air Force, Army, and DARPA.[71]

Analysts supporting these initiatives argue that hypersonic weapons can enhance deterrence and enable the U.S. military to counter threats from mobile missile launchers and advanced air and missile defence systems, which are crucial components of competitors' anti-access/area denial strategies.[72] In contrast, perspectives suggest that hypersonic weapons offer marginal to negligible warfighting advantages. Critics point out that the U.S. military has not yet defined specific mission requirements or operational concepts for these weapons.

The deployment of a functional hypersonic weapon by the United States before 2023 is unlikely. Unlike Russia and China, the U.S. prioritises the development of precision-oriented hypersonic weapons without nuclear warheads, which is a technically challenging endeavour compared with the less accurate Russian and Chinese systems.

China

Experts, including Tong Zhao from the Carnegie Tsinghua Center for Global Policy, believe that China's emphasis on hypersonic technology is driven by the need to counter specific security threats posed by advancing U.S. military technology,

68 Axe, 2019.
69 Raitasalo, 2019.
70 Office of the Under Secretary of Defense, 2021, pp. 2–3; see also Sayler, McCall and Reed, 2020.
71 Freedberg, 2020; Woolf, 2021.
72 Zakheim and Karako, 2019.

particularly the sophistication of regional missile defence. China's pursuit of hypersonic weapons, similar to Russia's endeavours, is driven by concerns that U.S. hypersonic weapons could enable a pre-emptive strike targeting China's nuclear arsenal and support infrastructure. This raises fears that U.S. missile defence systems could limit China's ability to retaliate against the United States. China successfully developed a DF-41 intercontinental ballistic missile capable of carrying a nuclear hypersonic glide vehicle, as reported by the U.S.–China Economic and Security Review Commission in 2014.[73] In February 2020, General Terrence O'Shaughnessy, then-commander of United States Northern Command, confirmed China's testing of a nuclear-capable intercontinental range hypersonic glide vehicle. This vehicle is designed to fly at high speeds and low altitudes, which complicates its ability to provide precise warnings. Indications suggest that in August 2021, China will potentially conduct a test involving a nuclear-capable hypersonic glide vehicle launched by the Long March rocket.[74]

In contrast to China's previous HGV launches using ballistic missiles, Long March employed a Fractional Orbital Bombardment System to launch HGV into orbit. The HGV then deorbits to reach its target, potentially providing China with a space-based global strike capability and reducing the warning time before a strike.[75]

Since 2014, China has conducted at least nine tests on DF–ZF glide vehicle. U.S. defence officials estimate the DF – ZF range to be approximately 1,200 miles, and there are indications that the missile may have the ability to perform evasive manoeuvres during flight.[76] While intelligence agencies have refrained from official confirmation, certain analysts have speculated that DF – ZF may have achieved operational status as early as 2020.[77] In August 2018, China successfully tested Starry Sky-2, a prototype hypersonic vehicle with nuclear capability.[78] Some reports suggest that Starry Sky-2 may become operational as early as 2025.[79] Officials in the United States chose not to provide any comments on the programme.[80]

Russia

Russia began researching hypersonic weapons technology in the 1980s, with an increased focus prompted by the deployment of missile defence systems in the U.S. and Europe. Accelerated efforts followed the United States' withdrawal from the Anti-Ballistic Missile Treaty in 2002.[81] In 2018, Putin voiced concerns over the U.S.

73 U.S.-China Economic and Security Review Commission, 2014, p. 292.
74 Sevastopulo and Hille, 2021.
75 Hadley, 2021.
76 The Economist, 2019.
77 U.S.-China Economic and Security Review Commission, 2015.
78 Yeung, 2018; see also: U.S.-China Economic and Security Review Commission, 2018, p. 220.
79 U.S.-China Economic and Security Review Commission, 2015, p. 20.
80 Gertz, 2018.
81 Borrie, Dowler and Podvig, 2019.

expansion of anti-ballistic missiles, fearing that it could devalue Russia's nuclear capabilities. He warned against the potential interception of all Russian missiles if no action was taken. Russia seeks hypersonic weapons that manoeuvre to penetrate U.S. missile defences, aiming to restore strategic stability.

Russia is actively developing two nuclear-capable hypersonic weapons: the Avangard and 3M22 Tsirkon (or Zircon). The Avangard is a hypersonic glide vehicle launched from an ICBM, granting it an "effectively 'unlimited' range". According to Russian news sources, Avangard became operational in December 2019. Tsirkon, a hypersonic cruise missile designed to be launched from both ships and submarines, has completed previously planned tests in 2021, with series deliveries beginning in 2022.[82]

3.4. Directed Energy (DE) Weapons[83]

According to the Department of Defense, directed energy (DE) weapons use concentrated electromagnetic energy to incapacitate, damage, disable, and destroy enemy targets.[84] DE weapons, with their potential cost advantages and virtually unlimited magazines, can be employed by ground forces for various missions, including short-range air defence (SHORAD), counter unmanned aircraft systems, counter rocket, artillery, and mortar tasks. They offer efficient and effective means of defending against missile salvos and swarms in unmanned systems. Theoretically, DE weapons might also be considered for boost-phase missile intercepts, leveraging their speed of light travel time; however, there are differing opinions on the affordability, technological feasibility, and utility of this application.[85]

High-powered microwave weapons, a subset of DE weapons, can non-kinetically disable electronics, communications systems, and improvised explosive devices. They also have potential as nonlethal "heat ray" systems for crowd control.

United States

Despite the U.S. researching directed energy since the 1960s, experts observe that "real DE programmes" have frequently fallen short of expectations. Despite the Department of Defense investing billions of dollars, many of these programmes have been cancelled.[86] Some researchers argue that advancements in commercial lasers could be used for military purposes.[87] Despite ongoing developments, DE weapons face challenges in terms of technological readiness. Issues include improving beam quality and control to meet military standards, as well as addressing the power,

82 Fediushko and Novichkov, 2021.
83 See: Sayler et al., 2023.
84 Joint Chiefs of Staff, 2020.
85 See: Miller and Rose, 2018.
86 Scharre, 2015, p. 4.
87 See: Ariel, 2015.

cooling, and size requirements for integration into existing platforms. In 2014, the U.S. Navy achieved a milestone by deploying the first operational U.S. DE weapon, the 30-kilowatt Laser Weapon System, aboard the USS Ponce. This prototype demonstrated capabilities such as warnings, blinding enemy forces, shooting down drones, disabling boats, and damaging helicopters.[88] The Navy is currently conducting tests and intends to deploy its 60 kW laser, HELIOS, on the USS Preble in accordance with its deployment schedule. Simultaneously, the army has outlined its plans to introduce its first "combat-relevant" laser, the 50 kW Directed Energy Maneuver-Short Range Air Defense, on Stryker fighting vehicles during Fiscal Year 2022.[89] Similarly, the Air Force is currently engaged in field evaluations of various DE systems designed to counter UAS. These assessments encompass both laser and high-power microwave systems.[90]

In Fiscal Year 2022, the Department of Defense sought a minimum of $578 million for unclassified research, development, test, and evaluation of Directed Energy, and a minimum of $331 million for the procurement of unclassified DE weapons.[91] Several initiatives within these programmes strive to align themselves with the Department of Defense's DE Roadmap. The roadmap charts an increase in DE weapon power levels, targeting approximately 300 kW by the Fiscal Year 2022 and further elevating it to approximately 500 kW by the Fiscal Year 2024.[92]

China

According to the United States – China Economic and Security Review Commission, China initiated the development of DE weapons in the 1980s. The country has demonstrated consistent advancements in the development of High-Power Microwaves (HPM) and progressively more potent high-energy lasers.[93] China has successfully engineered a mobile DE system known as LW-30, boasting a 30-kilowatt capacity. This system is specifically designed to engage unmanned aerial vehicles and precision-guided weapons.[94] Reports suggest that China is developing an airborne

88 Mizokami, 2019, p. 84.

89 See: Seapower Staff, 2021; Office of the Under Secretary of Defense, 2021.

90 See: Mizokami, 2020.

91 These figures include funding for DOD wide programmes as well as programmes managed by the Air Force, Army, and Navy. CRS analysis of FY2022 budget documents; for additional information, see: Appendix B in Sayler et al., 2023, pp. 228–256.

92 Although there is no consensus regarding the precise power level that would be needed to neutralize different target sets, it is generally believed that a laser of around 100 kW could engage UAVs, small boats, rockets, artillery, and mortar, whereas a laser of around 300 kW could additionally engage cruise missiles flying in certain profiles (i.e., flying across rather than at the laser). Dr. Jim Trebes, „Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?" Presentation at IDGA, October 21, 2020; and CRS conversation with Principal Director for Directed Energy Modernization Dr. Jim Trebes, November 17, 2020. Required power levels could be affected by additional factors such as adversary countermeasures and atmospheric conditions and effects.

93 See: U.S.-China Economic and Security Review Commission, 2017, p. 563.

94 See: Novichkov, 2018.

energy weapons pod. China has used or proposed DE weapons from the United States and its allies to interfere with military aircraft. Additionally, these weapons have been considered to disrupt the U.S. freedom of navigation operations in the Indo – Pacific region.[95]

According to the Defense Intelligence Agency, China is actively exploring DE weapons to disrupt satellites and sensors. These signs indicate China's limited capability to use laser systems for satellite sensors. The deployment of ground-based laser weapons to counter low-orbit space-based sensors is expected, with potential higher-power systems posing a threat to the structural integrity of non-optical satellites.[96]

Russia

Since the 1960s, Russia has actively pursued DE weapons research, with a specific emphasis on HELs. Reports suggest that Russia has operationalised Peresvet, a mobile ground – based HEL deployed alongside mobile intercontinental ballistic missile units. Although details about Peresvet, including its power level, are mostly unknown, some analysts speculate on its potential use for satellite dazzling and as a point defence system against unmanned aircraft systems.[97] The Deputy Defence Minister of Russia, Alexei Krivoruchko, has announced ongoing efforts to enhance the power level of the Peresvet, and intends to deploy it on military aircraft.[98]

Reports suggest that Russia is exploring HPMs and developing additional high-energy lasers capable of conducting anti-satellite missions.

3.5. Biotechnology

Biotechnology, drawing from life sciences, propels technological advancements with substantial implications for the U.S. military and global security. In 2018, a report from the Government Accountability Office highlighted the recognition of the potential impact of biotechnologies by key entities, including the Departments of Defense, State, and Homeland Security, as well as the Office of the Director of National Intelligence. Notably, low-cost gene editing tools, such as CRISPR, are at the forefront of technologies garnering attention in this context and[99] have the potential to alter genes or create DNA to modify plants, animals, and humans. Biotechnology has the potential to enhance military personnel's capabilities. The widespread adoption of synthetic biology, which allows for the creation of genetic codes that

95 See: Tate, 2020; Patrick and Ryan, 2020.
96 Defense Intelligence Agency, 2019, p. 20.
97 Defense Intelligence Agency, 2019, p. 23.
98 See: Hendrickx, 2020.
99 See: Gallo et al., 2018.

are not found in nature, may increase the number of entities capable of developing chemical and biological weapons.[100]

Similarly, the 2016 Worldwide Threat Assessment by the United States Intelligence Community identified genome editing as a possible tool for mass destruction. Moreover, biotechnology has the potential to create adaptive camouflage, cloaking devices, advanced, lighter, stronger, and potentially more self-healing bodies, and vehicle armour. Concerns have arisen about the ethical standards followed by U.S. competitors in the research and application of biotechnology, especially in the realms of biological weapons, genome editing, and more intrusive forms of human performance modification.

United States

In accordance with Section 1086 of the National Defense Authorization Act for Fiscal Year 2017 (Public Law 114-328),[101] the Donald Trump Administration released the National Biodefense Strategy, which outlines 'how the United States Government will manage its activities more effectively to assess, prevent, detect, prepare for, respond to, and recover from biological threats, coordinating its biodefence efforts with those of international partners, industry, academia, non-governmental entities, and the private sector'. However, analysts note that this strategy lacks a well-supported action plan and remains largely unimplemented. However, the Department of Defense lacks specific biotechnological research strategies. Unclassified U.S. biotechnology programmes for military applications have primarily focused on enhancing readiness, resilience, and recovery. DARPA has initiated various biotechnology programmes addressing battlefield medicine, diagnostics, prognostics, traumatic brain injuries, neuropsychiatric conditions, infectious diseases, and bioengineered threats to the U.S. food supply. DARPA's Safe Genes programme aims to protect service members from unintended or deliberate misuse of genome editing technologies.

Service laboratories have concluded a $45 million three-year joint research initiative in synthetic biology, focusing on innovative bio-based materials and sensors. The United States is exploring biotechnology and neuroscience applications to enhance soldier lethality, aiming for stronger, smarter, and more capable soldiers; however, there is no national framework for ethical considerations.

The Department of Defense, in response to Section 278 of the Fiscal Year 2021 National Defense Authorization Act, conducts a comprehensive evaluation of the military implications of emerging biotechnologies. This aims to provide insights and recommendations for potential legislative and administrative actions in the future. As mandated in Section 278, the Department of Defense assesses emerging

100 Government Accountability Office, 2018, p. 28.
101 Public Law No. 114-328 (2016) Section 2, Division A, Title X, § 1086.

biotechnologies for national security purposes, involving a direct comparison of the capabilities of the United States and other countries.[102]

China

Owing to the challenges of an ageing population and rising healthcare demands, China is actively advancing biotechnological research. Recognised as a crucial strategic priority under the Made in China 2025 initiative and emphasised in the ongoing five-year development plan, biotechnology reflects China's commitment to addressing healthcare and demographic concerns.[103] China is actively advancing biotechnology, particularly in genetic testing and precision medicine. In 2016, Chinese scientists achieved a milestone by using the CRISPR gene editing tool in humans. In 2018, a Chinese scientist, possibly with government approval, generated the first "gene edited babies". China houses National GenBank, one of the world's largest genetic information repositories, which includes data from the United States. These data can be used for personalised disease treatment or precise bioweapons. Although detailed information on China's military biotechnology applications is limited, the military civil fusion policy allows for the easy integration of civilian advancements for military purposes, highlighting the dual-use nature of biotechnological developments in China.

Reports indicate that China's Central Military Commission has allocated funding for projects in military brain science, advanced biomimetic systems, biological materials, human performance enhancement, and innovative biotechnology. Chinese military medical institutions are actively involved in CRISPR gene editing research. These initiatives highlight China's strategic interest and investment in advanced technologies with applications in both military and medical contexts.

Russia

Despite the release of BIO2020, a comprehensive government strategy aimed at enhancing Russia's biotechnology sector in 2012, biotechnology research in Russia still lags behind that in the United States and China.[104] BIO2020 outlines Russia's biotechnological research focus, which spans biopharmaceutics, biomedicine, industrial biotechnology, bioenergetics, agriculture, food biotechnology, forest biotechnology, environmental protection biotechnology, and marine biotechnology. Limited public information exists on how Russia may apply these dual-use technologies in the military or national security contexts. Concerns have arisen owing to attempts to assassinate a former double agent using a Novichok nerve agent, raising the possibility of exploiting biotechnological advancements for weaponising biological agents,

102 Public Law No. 116-283 (2021) Section 2, Division A, Title II, § 278.
103 See: CSET, 2021.
104 Russian Federation, no date.

including synthetic biology. The Soviet Union's history of maintaining a secretive biological weapons programme, Biopreparat, in violation of the 1972 Biological Weapons Convention adds to these concerns.

In August 2020, the End User Review Committee, comprising representatives from U.S. Departments of Commerce, State, Defense, Energy, and, when applicable, Treasury, found "reasonable cause" to suspect three Russian research institutes are linked to the Russian biological weapons programme.[105]

3.6. Quantum Technology

Quantum technology applies principles from quantum physics to practical applications, with significant potential implications for military sensing, encryption, and communications. Although not yet mature, reports from the Government Accountability Office indicate collective assessments by the Departments of Defense, State, Homeland Security, and the Office of the Director of National Intelligence. They suggest that „quantum communications could empower adversaries to establish secure communications beyond the reach of interception or decryption by United States personnel". Quantum computing poses the risk of potentially enabling adversaries to decrypt sensitive information and exposing U.S. personnel and military operations to targeted threats. Additionally, quantum technology could have military applications, such as quantum sensing, enhancing submarine detection and effectively making the oceans „transparent". Quantum sensing poses a potential threat to the resilience of U.S. sea-based nuclear deterrents, while also offering alternatives for positioning, navigation, and timing in GPS-degraded or denied environments. However, the application of quantum technologies in military contexts is challenging owing to the delicate nature of quantum states, which can be disrupted by slight movements, temperature variations, or other environmental factors. Physicist Mikkel Hueck noted that if quantum devices require extremely low temperatures, they can be costly, cumbersome, and energy-intensive. Achieving widespread adoption depends on notable advancements in materials science and fabrication techniques.

United States

According to an assessment by the Defense Science Board Task Force on Applications of Quantum Technologies, the U.S. military stands to benefit significantly from three key applications of quantum technology: quantum sensing, quantum computing, and quantum communications. The task force underscored the potential of QS to significantly enhance the capabilities of the Department of Defense for specific missions, providing precise navigation and timing in GPS-compromised environments. It also recognises the potential of quantum computers for decryption, signal processing, and AI applications, along with the enhancement of networking

105 Department of Commerce, 2020.

technologies through quantum communications. The assessment concluded that quantum sensing is ready for mission deployment, whereas quantum computing and communications are still developing early. The idea that quantum radar enhances the capabilities of the Department of Defense has been dismissed. DARPA and various military services allocate funding to diverse quantum technology programmes coordinated under Section 234 of the Fiscal Year 2019 NDAA to facilitate interagency collaboration in quantum information science and technology research and development.[106]

Under Section 220 of the Fiscal Year 2020 NDAA, each military department's secretary is authorised to establish quantum information science research centres. These centres can engage with public and private sector organisations to advance research in the field of quantum information science.[107] To date, the Navy has designated the Naval Research Laboratory as its Quantum Information Science Research Center, whereas the Air Force has chosen the Air Force Research Laboratory to serve both the Air and Space Forces. However, the army has stated that it currently has no plans to establish a quantum information science research centre.

As per Section 214 of the Fiscal Year 2021 NDAA, services must regularly update their list of technical challenges that quantum computers can address in the next one to three years. This section also mandates collaboration with small- and medium-sized businesses to provide quantum computing capabilities to the government, industry, and academic researchers addressing these challenges. In a related directive, Section 1722 mandates that the Department of Defense should assess the risks posed by quantum computers and evaluate the existing standards for post-quantum cryptography.

China

China has placed growing emphasis on advancing quantum technology research as a key focus within its broader developmental strategies.[108]

President Xi prioritised quantum communications and computing for major breakthroughs by 2030, aligning with China's National Science and Technology Innovation Program. In 2016, a quantum technology leader in China deployed the first quantum satellite for global quantum encrypted communications. In 2017, China solidified its leadership by hosting its first quantum-secured intercontinental videoconference.[109] China has invested heavily in terrestrial quantum communication networks. In 2016, a 2,000 kilometre quantum network linking Beijing and Shanghai was established. Ambitious plans are in place to expand the nationwide network in

106 Public Law No. 115-232 (2019) Section 2, Division A, Title II, § 234.
107 Public Law No. 116-92 (2019) Section 2, Division A, Title II, § 220.
108 Kania and Costello, 2018.
109 Office of the Secretary of Defense, 2019, p. 101.

coming years.[110] While quantum technology has developed primarily through academia, China aims to leverage these advancements for military applications, as outlined in its Thirteenth Five-Year S&T Military Civil Fusion Special Project Plan.

Russia

Russia's progress in quantum technology, similar to its advancements in AI, is significantly behind those of the United States and China. Analysts observe that Russia is potentially „5 to 10 years behind" particularly in the realm of quantum computing.[111] To expedite advancements, Russia announced in December 2019 a $790 million in quantum research over the next five years. The country has also adopted a five-year Russian quantum-technology roadmap to provide direction and structure for its quantum-technology development.[112] Although not exclusively focused on the military, details on how Russia plans to integrate these initiatives into its military operations are sparse in open sources.

4. Potential implications of Emerging Technologies for Warfighting

The rapid and relentless advancement of technology is a transformative force that has undeniably altered the warfare landscape. This profound influence not only redefined the methods by which nations engage in conflict but also prompted a paradigm shifts in the formulation and execution of defence strategies. Among the array of groundbreaking technologies at the forefront of this evolution are AI, autonomous systems, cyber capabilities, and biotechnology. These emergent technologies possess the unprecedented potential to revolutionise the very essence of warfighting, from the tactical intricacies of military operations to the broader realms of strategic thinking and ethical considerations.

AI, the cornerstone of this technological revolution, introduces a spectrum of possibilities that extend far beyond traditional military applications. The integration of AI into defence systems holds promise for enhancing decision-making processes, augmenting the efficiency of resource allocation, and optimising overall operational effectiveness. By leveraging advanced algorithms capable of processing vast volumes of data, military commanders can obtain real-time insights, enabling more informed and adaptive responses on the battlefield. However, this infusion of AI into military affairs is not without challenges, as it brings to the forefront concerns about

110 Kania and Costello, 2018.
111 See: Quirin, 2019.
112 Public Law No. 115-368, 2018.

algorithmic biases, the potential for unintended consequences, and ethical considerations surrounding the deployment of lethal autonomous weapons.

Similarly, autonomous systems encompassing unmanned aerial vehicles (UAVs), ground vehicles, and naval drones represent revolutionary forces reshaping the dynamics of warfare. The ability of these systems to perform an array of tasks without direct human intervention (from reconnaissance missions to targeted strikes) holds promise for reducing human casualties, while enhancing operational capabilities. However, the advent of autonomy in military systems has created profound ethical dilemmas. Delegating lethal decision-making to machines poses questions about accountability, unintended collateral damage, and the establishment of robust ethical frameworks that govern their use in compliance with international norms.

Cyber capabilities have emerged as a critical dimension of modern warfare as nations increasingly harness the power of digital domains to gain strategic advantages. The ability to conduct sophisticated cyberattacks on an adversary's infrastructure, disrupt communication networks, and compromise sensitive information has become a defining feature of contemporary conflicts. However, the inherently interconnected nature of cyberspace exposes vulnerabilities that extend beyond the traditional geopolitical boundaries. It is imperative to strike a delicate balance between offensive cyber operations and the need for resilient cybersecurity measures, underscoring the importance of establishing international norms that govern this evolving domain.

Biotechnology, with its revolutionary strides in genetic engineering and human augmentation, has introduced a new frontier in warfighting capabilities. The potential to enhance physical and cognitive abilities, coupled with personalised medical treatments, could redefine the capabilities of individual war fighters. However, the ethical considerations surrounding the creation of super soldiers, potential violations of human rights, and the geopolitical implications of imbalances in biotechnological advancements require careful scrutiny. Striking a balance between technological innovation and ethical boundaries is imperative to ensure responsible development and deployment of biotechnological advancements.

As space becomes an increasingly contested domain, its militarisation introduces novel challenges and opportunities for warfare. Nations have viewed space dominance by investing in satellite technologies for communication, surveillance, and navigation. The potential for satellite-based attacks introduces a new dimension to conflicts, raising concerns about the weaponisation of space and the need for international cooperation to prevent destabilising space-based confrontations.

Quantum technologies, which encompass quantum computing and communication, present a disruptive force that challenges existing paradigms of cryptography and secure communication. The development of quantum capabilities provides strategic advantages; however, the potential obsolescence of existing encryption methods raises concerns about the vulnerability of military communications. Adapting to the quantum era requires technological innovation as well as the establishment of new cybersecurity measures and international cooperation to address the asymmetric threats posed by quantum technologies.

Given these technological advancements, ethical and legal considerations are on the horizon. The integration of AI, autonomous systems, biotechnology, and other emerging technologies into warfighting requires the formulation of ethical guidelines and legal frameworks governing their use. Questions about the responsible use of AI, autonomy of lethal systems, and potential consequences of biotechnological enhancements require global collaboration to establish norms that prevent misuse and ensure accountability.

The introduction of emerging technologies also necessitates a fundamental re-evaluation of military doctrines and strategies. Nations must adapt to the changing landscape by integrating these technologies into existing frameworks while developing novel operational concepts. Harnessing the advantages of emerging technologies while mitigating their risks is essential for maintaining strategic relevance and ensuring preparedness on modern battlefields.

The multifaceted implications of emerging technologies for warfighting extend across various dimensions from the intricacies of military operations to the broader realms of strategic thinking and ethical considerations. As nations navigate this era of unprecedented technological progress, international cooperation has become paramount for establishing norms, regulations, and ethical guidelines that ensure responsible and accountable use. Striking a delicate balance between innovation and ethical considerations is imperative to navigate the evolving landscape of modern warfare and promote stability in an era characterised by rapid technological advancements.

4.1. Artificial Intelligence and Machine Learning

AI and machine-learning technologies offer unprecedented opportunities and challenges in warfare. These systems can enhance decision-making processes, optimise resource allocation, and improve overall operational efficiency. AI-driven algorithms can analyse vast amounts of data and provide commanders with real-time insights for strategic planning. However, reliance on AI also introduces vulnerabilities such as the risk of algorithmic biases, hacking, and ethical concerns regarding the use of lethal autonomous weapons.

4.2. Autonomous Systems

The development of UAVs, autonomous ground vehicles, and naval drones has reshaped battlefields. These systems can perform various tasks ranging from reconnaissance to targeted strikes without direct human control. While autonomous systems can reduce human casualties and enhance operational capabilities, there are ethical dilemmas surrounding the delegation of lethal decision-making to machines. The potential for unintended consequences and need for robust ethical frameworks pose challenges for policymakers and military leaders.

4.3. Cyber Warfare

The digital realm has become critical in modern warfare. Cyber capabilities enable nations to conduct sophisticated attacks on adversary infrastructures, disrupt communication networks, and compromise sensitive information. Offensive cyber operations can be conducted covertly, thus providing strategic advantages. However, the interconnected nature of cyberspace exposes vulnerabilities to potential retaliation and escalation. Establishing international norms and rules for cyber warfare is essential for mitigating the risks associated with this emerging domain.

4.4. Biotechnology and Human Augmentation

Advances in biotechnology, including genetic engineering and human augmentation, can redefine war fighter capabilities. Enhanced physical and cognitive abilities as well as personalised medical treatment could provide a significant advantage on the battlefield. However, ethical concerns have arisen regarding the potential to create super soldiers, violate the principles of human rights, and exacerbate existing geopolitical tensions. Balancing innovation with ethical considerations is crucial for the development and deployment of biotechnological advancements.

4.5. Space Dominance

Space has become a contested domain with nations investing in space-based technologies for communication, surveillance, and navigation. The militarisation of space introduces the potential for satellite-based attacks, which disrupt adversary capabilities and communication networks. As nations compete for space dominance, there is a growing need for international cooperation and the establishment of norms to prevent the weaponisation of space and mitigate the risks of space-based conflicts.

4.6. Quantum Technologies

The development of quantum computing and communication has implications for cryptography, intelligence gathering, and secure communication. Quantum technologies can potentially render existing encryption methods obsolete, posing challenges to securing military communication. Nations investing in quantum capabilities gain a strategic advantage; however, this also raises concerns regarding the potential for asymmetric threats and the need to adapt cybersecurity measures in the quantum era.

4.7. Ethical and Legal Considerations

The integration of emerging technologies into warfighting necessitates the careful consideration of ethical and legal frameworks. Questions surrounding the responsible use of AI, autonomy of lethal systems, and potential consequences of biotechnological enhancements require international collaboration to establish ethical guidelines. Developing legal norms governing the use of emerging technologies in armed conflicts is crucial for preventing misuse and ensuring accountability.

4.8. Adaptation of Military Doctrine

The introduction of emerging technologies requires a fundamental shift in military doctrine and strategy. Nations must adapt to the changing landscape by integrating these technologies into existing frameworks while developing new operational concepts. Harnessing the advantages of emerging technologies while mitigating their risks is essential for maintaining strategic relevance on modern battlefields.

The dynamic landscape of modern warfare has been increasingly shaped by the rapid evolution of emerging technologies, presenting a myriad of potential implications across various domains. At the strategic level, nations are compelled to reconsider traditional doctrines and strategies to effectively integrate cutting-edge technologies into their defence capabilities… Operational implications extend to the battlefield, where advancements in AI, autonomous systems, and cyber capabilities are transforming the nature of conflict and military operations.

Ethical considerations are significant in this era of technological progress, as the deployment of advanced weaponry and surveillance systems raises concerns about the potential for unintended consequences and civilian casualties. Striking the right balance between innovation and ethical considerations is essential for ensuring that the development and application of emerging technologies align with international humanitarian laws and ethical norms. For instance, the ethical dimensions of autonomous weapons require careful scrutiny to prevent loss of human control and mitigate the risk of unintended consequences.

On the legal front, there is a pressing need for the international community to collaborate and establish clear regulations governing the use of emerging technologies in warfare. International law must adapt to address the challenges posed by novel weapons systems, cyber warfare, and other technologically driven aspects of conflict. This requires a proactive approach to developing and updating legal frameworks that can effectively govern the responsible use of emerging technologies while holding violators accountable.

Collaboration among nations is paramount in addressing the potential consequences of emerging warfare technologies. The establishment of international norms and agreements will contribute to a more stable and secure global environment. A shared commitment to ethical guidelines can serve as a foundation for responsible behaviour, preventing the misuse of advanced technologies that could escalate conflicts and endanger global security.

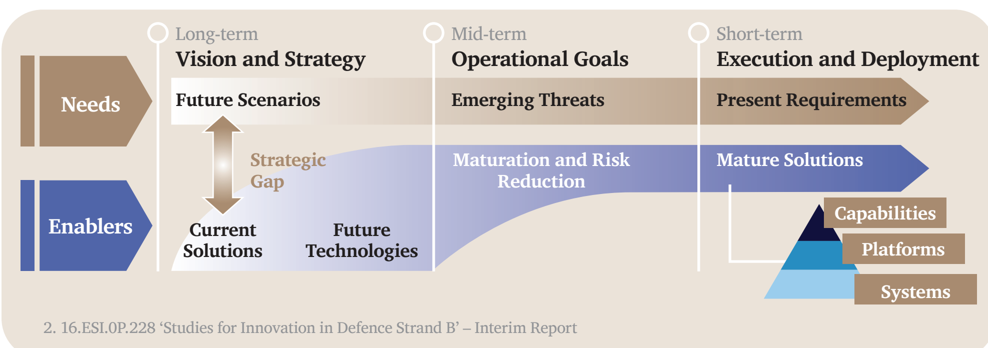
As nations continue to invest heavily in the development of emerging technologies for warfighting, it is crucial for the international community to foster collaboration and establish comprehensive norms, regulations, and ethical guidelines. Striking a balance between innovation and ethical considerations is imperative for navigating the complexities of modern warfare and ensuring a stable and secure global landscape in the face of rapid technological advances

5. Defence innovation: future perspective

Rapid technological changes, including defence, have shaped the pace of life in society. The level of protection a state offers its citizens depends on its ability to defend itself against technological interference. Strategic and technological forecasting is crucial for the European Armed Forces to invest in their future capabilities. The concept of innovation is widely used across various fields, but there is ambiguity about what qualifies as „innovative”. Over time, innovation shifted from having a negative connotation to becoming a key factor in long-term economic growth and international competitiveness.

Innovation involves creating and applying new products, services, and processes, including adapting existing technologies to different challenges. Integrating diverse innovative technologies into defence can reduce the initial investment risks and the time to deliver new military capabilities. The objective is not only to conceive novel concepts, but also to provide added value to end users, with a focus on enhancing military capabilities. Innovation in the defence sector can take various forms. Breakthrough innovations significantly affect operational methods and market dynamics, leveraging enabling factors to surpass traditional progress. By contrast, gradual innovations aim to optimise existing products, services, or processes without fundamentally altering them.

Table 1 – Future scenarios determined at the stage of long, mid, and short vision and strategy[113]



113 European Defence Agency, 2017, p. 9.

Successful defence sector innovations require a blend of breakthroughs and gradual innovation capabilities to meet future defence requirements. Organic innovation occurs in response to new threats and gaps in strategic capabilities. Long-term vision and strategies are vital for anticipating challenges and allocating resources to emerging technologies. Although structured processes are essential to innovation, they must be streamlined to encourage creativity. Unlike traditional defence-led models, recent trends have shown that civil and commercial markets drive innovation in fundamental technologies. The European Defence Agency prioritises collaboration with nontraditional research communities to efficiently access groundbreaking research. The Captech Technology Group within the agency plays a key role by establishing a network of experts from the participating Member States to address specific technology areas.

The European Defence Agency has implemented a comprehensive tool chain to enhance innovation and integrate new subjects and technologies into defence. This tool chain covers all stages, from identifying technology and project concepts to enhancing the overarching strategic research programme, known as the Overarching Strategic Research Agenda.[114]

1. The "Technology Watch" initiative is a recent undertaking launched by the European Defence Agency. Its aim is to empower research and technology experts to actively seek and disseminate new information among their peers. Furthermore, a dedicated technological forecasting methodology is devised to facilitate the long-term identification of emerging technologies.
2. Captechs identify the technologies discussed in the Technology Watch tool and forecasting workshops. In the second stage, the collective expertise of all the participating member states is harnessed for technological assessment. This involves determining the best practices and implementing customised processes intended to evaluate interest in a specific technology.
3. The final stage involves selecting the most promising technologies to incorporate into an Overarching Strategic Research Agenda.

The analysis of the above time horizons to achieve maturity has been categorised into five different perspectives, each with a specific timeframe:

1. Short-term perspective: This indicates that maturity is achieved within the next five years. This is the most immediate timeframe, suggesting a relatively quick realisation of goals or completion.
2. Short- and medium-term perspectives: This timeframe suggests that maturity will be achieved between 5 and 10 years. It covers both the short-term and beginning of the medium-term range, indicating a moderate waiting period.
3. Short- and medium-term perspectives: This timeframe suggests that maturity will be achieved between 5 and 10 years. It covers both the short-term and beginning of the medium-term range, indicating a moderate waiting period.

114 *Disruptive Defence Innovations Ahead!*, no date.

4. Short- and medium-term perspectives: This timeframe suggests that maturity will be achieved between 5 and 10 years. It covers both the short-term and beginning of the medium-term range, indicating a moderate waiting period.
5. Short- and medium-term perspectives: This timeframe suggests that maturity will be achieved between 5 and 10 years. It covers both the short-term and beginning of the medium-term range, indicating a moderate waiting period.

Each perspective helps plan and set expectations based on the anticipated timeframe for maturity. This compilation is derived from an analysis of long-term technological trends outlined in the ability development plan, along with groundbreaking technologies identified by Captech at the European Defence Agency during the Overarching Strategic Research Agenda process.[115]

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6. Conclusions and recommendations

In scrutinising the dynamic landscape of emerging military technologies across EU Member States, it becomes increasingly apparent that the region stands at a pivotal crossroads. Innovation, security imperatives, and ethical considerations converge, creating a complex matrix that requires a nuanced analysis. The interplay of cutting-edge technologies, geopolitical dynamics, and ethical frameworks presents a multifaceted puzzle that necessitates a comprehensive examination to comprehend fully.

Our journey highlights the latest achievements, shedding light on the strides made in various technological domains that contribute to the defence apparatus. Simultaneously, we confront the challenges that have arisen in this era of rapid technological evolution and address concerns related to cybersecurity, geopolitical tensions, and the ethical dimensions of deploying advanced military capabilities.

Moreover, our scrutiny extends beyond the present moment, with the aim of forecasting development prospects. By doing so, we seek to anticipate the trajectory of European defence systems in the face of evolving global dynamics, thereby providing insights into the strategic considerations that will shape the region's security landscape.

Ultimately, the overarching objective is to understand how these new technologies are not only reshaping the face of European defence, but also to discern the far-reaching implications they hold for the broader spectrum of regional security. By navigating the intricate web of innovation, security imperatives, and ethical frameworks, we aspire to contribute to a comprehensive understanding of the intricate

115 See: European Defence Agency, 2019.

tapestry that defines the contemporary landscape of European defence in the age of advanced technologies.

This exploration unearthed several key insights and issues that demand attention from policymakers, defence experts, and the broader public. Several noteworthy findings emerged from this examination.

1. **Technological Leapfrogging and Competitiveness.**
   EU Member States are actively engaging in a technological arms race driven by the imperative to maintain military competitiveness in an era characterised by rapid advancements. The pursuit of cutting-edge capabilities reflects a strategic commitment not only to keep pace with global developments but also to potentially lead in certain areas. Member States must strike a delicate balance between cooperation and competition to foster an environment that promotes innovation without compromising security.
2. **Collaboration Challenges and Opportunities.**
   A collaborative landscape presents both challenges and opportunities. While the European Defence Fund and other initiatives aim to foster cooperation, Member States must navigate political, economic, and technological divergence. Overcoming these challenges demands a shared vision, standardised protocols, and commitment to the common security interests of the EU. Enhanced collaboration has the potential to streamline research efforts, optimise resource allocation, and amplify the impact of emerging military technologies.
3. **Ethical and Legal Implications.**
   The deployment of emerging military technologies has raised profound ethical and legal questions. As autonomous systems, AI, and cyber capabilities become integral to defence strategies, there is an urgent need for a robust ethical framework. Establishing clear guidelines for the ethical use of military technologies is not only a moral imperative, but also essential for maintaining public trust and adherence to international norms. Striking the correct balance between innovation and responsible use requires a multidisciplinary approach involving policymakers, ethicists, and technologists.
4. **Strategic Autonomy and Global Partnerships.**
   The quest for strategic autonomy is a defining feature of the EU's approach to emerging military technologies. However, this should not be viewed as an isolation. A nuanced strategy involves the careful calibration of autonomy and the forging of global partnerships. Recognising the interconnected nature of security challenges, the EU must leverage its technological strength to contribute to international stability. Collaborative ventures with like-minded nations and organisations can enhance the effectiveness of security efforts while mitigating the potential risks associated with unilateralism.
5. **Resilience and Adaptability in the Face of Uncertainty.**
   The dynamic nature of technological advancement introduces uncertainty. Member States must cultivate resilience and adaptability in their military

strategies. Thus, a flexible approach that accommodates rapid technological changes is crucial. Investing in versatile capabilities, fostering a culture of continuous learning, and prioritising agility in decision-making are essential components of a resilient defence posture.

6. **Public Engagement and Transparency.**
   The implications of emerging military technologies extend beyond defence establishments to impact society. Public engagement is paramount for shaping policies that align with societal values and concerns. Transparency in the development and deployment of military technologies fosters public trust and ensures democratic supervision. Member States should actively communicate their strategies, risk assessments, and ethical considerations to build a shared understanding of the role of technology in national and collective security.

In conclusion, the trajectory of emerging military technologies within the EU Member States has significant implications for a region's security landscape. Successful navigation of this complex path demands a nuanced approach that strikes a delicate balance between competition and collaboration, autonomy and global partnerships, and innovation and ethical considerations. The decisions of EU Member States to steer this trajectory will undoubtedly shape the future dynamics of security and defence in the region.

Maintaining a competitive edge while fostering collaboration among Member Statesis crucial for bolstering the EU's collective defence capabilities. The pursuit of technological advancements should be accompanied by a commitment to work together to address common security challenges. By fostering a cooperative environment, Member States can pool resources, share expertise, and enhance interoperability, thereby creating more robust and unified defence postures.

Simultaneously, the pursuit of autonomy in military technologies should be tempered by recognising the interconnected nature of global security. Striking a balance between autonomy and strategic partnerships with like-minded nations is essential for navigating the ever-evolving geopolitical landscape. Collaborative efforts on defence projects not only enhance the EU's technological prowess but also contribute to fostering stronger diplomatic ties and alliances, reinforcing the region's position on the international stage.

Innovation should be pursued ethically to ensure that emerging military technologies adhere to the principles of responsible innovation. Member States must prioritise the development of technologies that align with international norms, human rights standards, and legal frameworks. This commitment to ethical practices will not only enhance the legitimacy of the EU's defence initiatives but also mitigate potential risks and concerns associated with the deployment of advanced military capabilities.

Furthermore, societal engagement should be a central tenet of the EU's approach to developing military technologies. Transparency, public discourse, and civil society's involvement in decision-making processes are vital for fostering public trust and ensuring that technological advancements align with the values and expectations of EU citizens. By engaging the public, Member States can address concerns related to the ethical implications of military technologies and garner support for strategic initiatives.

As EU Member States chart their courses in emerging military technologies, they must remain anchored in the principles of responsible innovation, international cooperation, and societal engagement. These pillars will serve as the foundation for the future, in which military technologies will contribute to the interests of peace, stability, and shared prosperity in the European Union and beyond.

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