Review

Research and development of strategic technologies for military and defense missions: A review

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ABSTRACT

This paper provides a comprehensive view of the impact of strategic technologies on modern warfare. The paper asserts that this is not a series of individual advances but a composite revolution shaped by the convergence of many important technologies such as artificial intelligence, robotics and automation, hypersonic weapons, quantum technology, space technology and cyber technology, and biotechnology, which have profound impacts on military operations. The analysis synthesizes assessments from defense organizations, academic research, and government to highlight the significant changes in operations and the erosion of traditional deterrence models. The paper concludes by proposing policy solutions for Vietnam's defense modernization to effectively respond to the challenges and take advantage of the important opportunities brought by these global trends.

Keywords: Strategic technologies; Warfare; Science and technology policies.

1. INTRODUCTION

Global security is being fundamentally transformed by the rapid development and proliferation of strategic and disruptive technologies. These advancements are increasingly influencing all aspects of life, from civilian electronics and commerce to the most critical national security functions [1]. These technologies have a profound impact on every aspect of life, defense and security, etc. The technologies under focus include artificial intelligence (AI), autonomous systems, quantum technologies, biotechnology, space, hypersonic systems, and next-generation communications networks. These innovative technologies are providing new avenues for their militaries to become more effective, resilient, cost-efficient, and sustainable. They are seen as a means to address immediate capability shortfalls and to meet long-term defense targets [1, 2]. The strategic context demands a coherent approach to the development and adoption of dual-use technologies - those with both commercial and defense applications to strengthen a nation's or alliance's technological edge. This new reality requires not only fostering the development of new technologies but also protecting a nation's own innovation ecosystems from interference and manipulation by potential adversaries and competitors [3]. In the next section, we will discuss some strategic technologies and their impact on the way of warfare.

2. STRATEGIC TECHNOLOGIES AND THEIR IMPACT ON WARFARE

2.1. The AI

AI and machine learning are now deeply integrated into the veins of modern warfare, fundamentally altering its character and enhancing military capabilities across all levels of conflict [4]. These technologies are being leveraged for a wide range of applications beyond traditional combat. One of the most significant uses is in intelligence, surveillance, and reconnaissance (ISR), where advanced algorithms can analyze vast amounts of data - far more than human analysts could process - to identify patterns, predict enemy behavior, and optimize military strategies in real time [4]. The ability to process this data at a "speed and scale" far beyond human capacity provides a significant advantage in all-domain operations [6]. Beyond the battlefield, AI is poised to

revolutionize military logistics and readiness. Traditional material planning methods, which rely on historical data and are often plagued by inefficiencies and stockouts, are proving inadequate in the face of contemporary challenges. AI and machine learning-based planning methods are uniquely positioned to address this by leveraging expanded data environments, identifying nonlinear relationships, and adapting to changing patterns in real time [7, 8]. This transition promises to enhance accuracy, resilience, and strategic responsiveness, ensuring that military logistics operations remain robust even in the face of evolving adversarial threats. The application of AI in combat has led to the emergence of a new class of weapon systems: lethal autonomous weapon systems (LAWS). These systems use sensor suites and computer algorithms to independently identify targets and employ an onboard weapon without manual human control. The power of these systems is amplified by the ability to operate in "swarms," where numerous unmanned vehicles communicate with each other and adjust tactics as circumstances change. This "multiplier force effect" could make it impossible for an enemy to execute a command or respond, thereby altering the very nature of warfare [8, 9].

2.2. Robotics and automation technology

The integration of robotics and automation is fundamentally reshaping modern warfare, driven by rapid advancements in artificial intelligence (AI) and sensor technologies. These systems, including unmanned aerial and ground vehicles, are increasingly used for a variety of critical military applications, such as reconnaissance, logistics, and hazardous missions like explosive ordnance disposal, thereby reducing the risk to human personnel. Autonomous systems act as a powerful "force multiplier," allowing militaries to operate with greater efficiency and in environments too dangerous for humans. A notable development is the use of "swarms," where numerous unmanned vehicles communicate and cooperate to overwhelm enemy defenses, representing a new combat capability that could make it impossible for an enemy to respond effectively. This shift signifies a new warfighting paradigm defined by speed, precision, and the increasing reliance on autonomous operations to achieve strategic objectives [10, 11].

2.3. The hypersonic and directed energy weapons

The development of hypersonic weapons represents a paradigm shift in military technology, fundamentally questioning the foundations of strategic security and deterrence. Hypersonic weapons, which travel at speeds greater than Mach 5 (approximately one mile per second), come in two main classes: hypersonic boost-glide vehicles (HGVs) and hypersonic cruise missiles (HCMs) [12]. Unlike ballistic missiles, which follow a predictable flight path, HGVs and HCMs can glide and maneuver within the upper atmosphere, making them exceedingly difficult for traditional missile defense systems to track and intercept. The global competition to field these weapons is intense, particularly among the world's great powers. Russia and China are widely considered to be leading this race, having reportedly deployed operational HGVs. In contrast, the United States has faced a series of delays and technological setbacks in its hypersonic program, highlighting significant questions about the operational performance of its systems in real-world scenarios. The unparalleled speed and maneuverability of hypersonic weapons have a profound effect on strategic stability by compressing warning times to mere minutes [12, 13]. This drastic reduction in reaction time amplifies the risk of miscalculations and accidental escalation, particularly in moments of crisis. Traditional deterrence, which relies on the certainty of a devastating retaliatory strike, is challenged by these new weapons. The unpredictability of their flight paths and their ability to evade detection erode the very foundation of this certainty [13].

As a counter to the growing threat of hypersonic weapons and other strategic capabilities like drone swarms, militaries are actively developing directed energy weapons (DEWs). These systems, which include high-energy lasers (HEL) and high-power microwaves (HPM), convert chemical or electrical energy to radiated energy and focus it on a target, causing physical damage

[14]. DEWs are seen as a critical element of modern air defense, offering a cost-effective alternative to traditional missile-based systems. Directed energy weapons have several key advantages. The cost per shot could fall to nearly zero, while the rate of fire could theoretically exceed any mechanical system. For example, the UK developed DragonFire laser weapon is capable of engaging targets like drones and mortar rounds at a classified range and reportedly costs less than 13 pounds per shot [14, 15].

2.4. The quantum technology

Quantum technology, which exploits the fundamental laws of nature, is poised to have a transformative impact on military operations. The potential applications span a broad range of sectors, but are particularly relevant to defense in the areas of sensing, communication, and computing. Quantum computers with their unprecedented computational power are expected to transform various aspects of modern military operations. Unlike classical computers, quantum systems can process complex problems involving vast amounts of data at speeds previously unattainable. Key military applications include: Quantum algorithms can optimize routes, resources, and maintenance schedules for complex logistical systems in real time, even under uncertain conditions; Supports high-fidelity simulations of physical systems, such as nuclear reactions, material sciences, and weather patterns. This can improve strategic planning, weapon design, and battlefield readiness; Quantum-enhanced machine learning can analyze large datasets from satellites, sensors, and intelligence sources faster and more accurately, strengthening decision-making and situational awareness; Quantum computing could enhance radar signal processing, electronic warfare, and the coordination of missile defense systems by solving highly complex optimization problems [16].

Quantum sensors can detect extremely small changes in physical parameters, such as magnetic and electric fields, with unprecedented precision and stability. This makes them ideal for a variety of critical military applications, including detecting enemy submarines or mines, monitoring weak radio communications, and providing early warning of missile launches. The quantum sensing technology is used in real-world conditions, seeking to develop sensors that are resilient to vibrations and electromagnetic interference. These sensors could potentially identify the signature of a nuclear weapon or create detailed maps of enemy territory, providing a significant advantage in planning operations [16, 17].

Quantum communication offers the potential for creating secure channels for information transfer that are resistant to eavesdropping. Quantum cryptography, particularly through Quantum Key Distribution (QKD), uses the principles of quantum mechanics to encode data in a way that is impossible to copy or intercept without changing the system's state. From a military perspective, this technology could make military communication almost immune to interception, enabling highly secure command and control systems and intelligence sharing [18].

2.5. The technology of space and cyber

Space and cyber technologies have evolved into critical domains of contemporary military operations, fundamentally reshaping the nature of conflict. Outer space, now widely considered a war-fighting domain, is essential for a wide range of military functions, including intelligence, surveillance, reconnaissance, and navigation. However, the proliferation of dual-use satellite systems has made them prime targets for electronic warfare, directed-energy weapons, and anti-satellite weapons. Meanwhile, cyberspace has emerged as a "borderless" and "space-less" battlefield, enabling a new form of asymmetric warfare where smaller nations and non-state actors can inflict significant damage on critical infrastructure without relying on traditional military power [19]. The convergence of these domains is particularly profound, as cyberattacks can be used to hijack or disable satellites and their ground control stations, creating a "strategic gray zone" where it is difficult to attribute attacks and, consequently, hinders traditional deterrence. The speed

and complexity of these attacks amplify the risk of miscalculation and accidental escalation, introducing new challenges to global security [20, 21].

2.6. The biological technology

Biotechnology has emerged as a dual-use field with significant implications for military operations, offering both defensive potential and profound new threats to national security. On one hand, it enables advancements in soldier enhancement, such as the use of exoskeletons to improve mobility and biomaterials that are stronger, lighter, and self-healing for military platforms and infrastructure [22]. Biosensors can also be deployed to provide early warnings of environmental threats like pathogens or toxic chemicals on the battlefield. Conversely, the dual-use nature of this technology means that research for legitimate purposes can be repurposed for harmful applications, and the democratization of these biothreats to non-state actors, including terrorist groups, is a key concern, given that the required materials and infrastructure are often low-cost and widely available [23]. This threat is further amplified by the convergence of biotechnology with AI, giving rise to "cyberbiosecurity" where generative AI can be used to develop novel pathogens or exploit digital vulnerabilities in research facilities to facilitate an attack. The lack of clear attribution in such a cyberbiological attack complicates traditional deterrence and response efforts, creating a dangerous and complex security landscape for the future of warfare [22, 23].

3. POLICY RECOMMENDATIONS FOR VIETNAM'S MILITARY SCIENCE AND TECHNOLOGY

In the face of an increasingly complex and unpredictable external security environment and the ultrafast change in new technologies impacting the operational method, Vietnam has made military modernization a strategic priority. The country has set an official target of building a "modern military" from 2030 onward to meet the requirements of safeguarding the homeland and responding to high-tech warfare [24]. The political leadership has emphasized the need for "breakthroughs" in military innovation and digital transformation, with the explicit goal of building a "digital warrior" and adopting the achievements of the Fourth Industrial Revolution in the defense sector [25]. Especially, resolution No. 57-NQ/TW of the Political Bureau represents a strategic policy for Vietnam, focusing on achieving breakthroughs in science, technology, innovation, and national digital transformation. A key task outlined in the resolution is to establish mechanisms that encourage public procurement of products resulting from domestic scientific research and development, providing a reliable market for local high-tech firms. The overall aim is to enhance national technological capacity, reduce reliance on foreign platforms, and ensure technological sovereignty [26].

Based on this strategic direction and the challenges of modern warfare, we recommend some policies for the nation's military science and technology development that cope with them.

3.1. Prioritizing to invest in strategic and dual-use technology

We should continue to focus and prioritize budget allocations for research and development (R&D) tasks aimed at mastering strategic and foundational technologies. This approach is adopted with developing nations such as Vietnam, for example, the Vietnamese Government announced the Launching Ceremony of 3 Strategic Technology Networks: Quantum Technology, Cyber Security Network and Vietnam Aviation, Space, Unmanned Aerial Vehicle (UAV) Network on August 25, 2025. This is more effective than distributing funds thinly across many projects, which was a past practice. Promoting dual-use production which adopting a strategy that promotes the dual-use of production lines - for both defense and economic purposes - is crucial for building a self-reliant defense industry. This not only enhances defense capabilities but also contributes to economic development, generating more resources for technological modernization and human resource development within the defense industry. This should be leveraged to encourage the local

design, manufacturing, and technology transfer of key components, such as semiconductor chips, to reduce dependency on foreign platforms and enhance national autonomy [24, 26].

3.2. Pushing a private-public-academic alliance

To ensure technological sovereignty, we should build a strategic alliance between the state, academia, and enterprises. This model, which is already being implemented to some extent, is essential for mastering core technologies, creating "Made by Vietnam" products, and enhancing national technological capacity. The government should continue to support and encourage, and foster a "three pillars" alliance among the state, academia and enterprises, a model seen as essential for mastering core technologies and creating "Made by Vietnam" products in their role as the "core driver" of the high-tech defense industry cluster [27].

3.3. Developing high-quality human resources

Vietnam should have a long-term plan to develop high-quality human resources should be fully supported and implemented. The plan aims to increase the number of students pursuing advanced degrees in science, technology, engineering, and mathematics (STEM), with specific targets for graduates in digital technology, AI, quantum technology and biotechnology. Policies should be put in place to attract and retain talented lecturers and researchers. The Ministry of Defense should also focus on building a highly skilled workforce capable of designing and producing advanced military technologies, which is a key requirement for self-reliance. We should continue to innovate its training content and methods, leveraging the achievements of the 4th Industrial Revolution, such as virtual reality simulations, to improve the skills of its personnel [5, 28].

3.4. Enhancing international cooperation and technology transfer

Vietnam's defense modernization depends on international cooperation and technology transfer to acquire capabilities that cannot be developed domestically. The country should continue to expand its defense diplomacy. Building an independent defense industry is a strategic goal, international partnerships are necessary to maintain a technological edge and navigate the complexities of great power competition. The government should actively promote collaborations with international partners in key technological areas to help diversify supply chains and provide access to cutting-edge research and development in fields like cybersecurity, AI, quantum and space technologies [27, 28].

By adopting these policy recommendations, Vietnam can strengthen its military-industrial complex, accelerate its technological transformation, and build a modern, self-reliant defense force capable of safeguarding national sovereignty in a rapidly changing world. Pioneering in the policy of Resolution No. 57-NQ/TW of the Political Bureau and and No.3488-NQ/QUTW of Central Military Commission represent a strategic policy for Vietnam, Academy of Military Science and Technology Institute (AMST) is a leading multidisciplinary science and technology institute of the Vietnam Military, focusing on a number of strategic technologies such as: Quantum technology; Satellite imitation technology; Unmanned vehicle positioning and Navigation technology against electronic warfare; Integrated Electronic circuit technology; Lidar Technology; Camouflage Technology; Hypersonic and Hypersonic missile simulation Computing technology; Directed energy weapon technology; Military robot technology; High Power laser technology; Biological technology; Technology for manufacturing heat-resistant Alloys for missiles; Special materials technology for weapons; INS-Non-GNSS positioning. Strengthening scientific and technological cooperation with domestic and international partners. AMST also developed high-quality human resources through self-training and training exchanges at prestigious research institutions abroad. The synchronous implementation of such measures will be a solid foundation for the manufacturing of strategic products to serve the military, which meet the requirements of safeguarding the homeland and responding to high-tech warfare.

4. CONCLUSIONS

In summary, strategic technologies are fundamentally reshaping the character of modern warfare, driving a paradigm shift akin to previous revolutions in military affairs brought about by innovations like gunpowder or nuclear weapons. The convergence of AI, autonomous systems, hypersonics, and developments in space and cyber is creating a new warfighting regime defined by speed, precision, and information superiority. This technological fusion enables more accurate and destructive weapon systems, but also shifts the focus from traditional firepower to the power of data and advanced command and control. Quantum technology opens unprecedented opportunities in science and technology. Space assets are becoming increasingly critical for tracking and countering hypersonic threats. Meanwhile, cyber warfare provides a new vector for attack on the interconnected, information-dependent systems that underpin all modern militaries. This synergy creates a more complex, faster-paced, and potentially more destructive form of warfare, where the lines between traditional military domains are blurred and the consequences of an attack can be instantaneous and far-reaching. Finally, we have proposed some policies for military science and technology in Vietnam, a developing country, to cope with this great impact.

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TÓM TẮT

Nghiên cứu, phát triển các công nghệ chiến lược phục vụ nhiệm vụ quân sự, quốc phòng

Bài báo này đưa ra một cái nhìn toàn diện về tác động của công nghệ chiến lược lên chiến tranh hiện đại. Bài báo khẳng định rằng đây không phải là một loạt những tiến bộ riêng lẻ mà là một cuộc cách mạng tổng hợp được hình thành bởi sự hội tụ của nhiều công nghệ quan trọng có tác động sâu sắc đến hoạt động tác chiến quân sự như trí tuệ nhân tạo, rô bốt và tự động hoá, vũ khí siêu thanh, công nghệ lượng tử, công nghệ vũ trụ và công nghệ mạng, và công nghệ sinh học, những công nghệ này có tác động sâu sắc đến hoạt động tác chiến quân sự. Phân tích này tổng hợp các đánh giá từ các tổ chức quốc phòng, nghiên cứu học thuật và chính phủ để làm nổi bật những thay đổi quan trọng trong hoạt động tác chiến và xói mòn các mô hình răn đe truyền thống. Bài báo kết thúc bằng việc đề xuất các giải pháp chính sách cho quá trình hiện đại hóa quốc phòng cho Việt Nam nhằm ứng phó hiệu quả những thách thức và tận dụng cơ hội quan trọng do những xu hướng toàn cầu này mang lại.

Từ khóa: Công nghệ chiến lược; Phương thức tác chiến; Chính sách khoa học và công nghệ.