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Outlook into the future of warfare with innovation race regarding human enhancement

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Abstract

The future of warfare is undergoing a transformative shift driven by the rapid advancement of human enhancement technologies and their integration with artificial intelligence. These innovations promise to revolutionise military operations by augmenting the physical and cognitive capabilities of soldiers, enabling unprecedented efficiency and adaptability on the battlefield. This paper explores the profound implications of this innovation race, analysing the strategic, operational and geopolitical impacts of human enhancement technologies. While these advancements offer significant advantages, such as enhanced soldier performance and strategic dominance, they also introduce complex ethical, legal and societal challenges. Unequal access to enhancements risks exacerbating global inequalities, while the blurred lines between soldiers and technological assets challenge existing international norms. This study employs a game-theoretic model to evaluate the dynamics of competition in human enhancement and artificial intelligence, highlighting potential risks such as arms-race instabilities and ethical dilemmas. Ultimately, this research underscores the urgent need for comprehensive frameworks to guide the responsible development, integration, and regulation of human enhancement technologies in military contexts, ensuring their deployment aligns with ethical principles and global security objectives.

Introduction

The future of warfare is rapidly evolving, shaped by the unprecedented pace of technological advancements and the increasing complexity of modern conflicts. Technological sophistication, hybrid operations, and the integration of autonomous systems are becoming defining characteristics of military strategies. As these transformations unfold, the success of any nation on the modern battlefield increasingly hinges on its ability to adapt to emerging forms of warfare, leverage advanced technologies cost-effectively, and main-

tain resilient and flexible military structures. This shift necessitates a holistic understanding of the opportunities and challenges posed by disruptive innovations, particularly in the realms of human enhancement and artificial intelligence.[1]

Amid this transformation, human enhancement technologies have emerged as a critical area of innovation, with profound implications for military operations. These technologies promise to amplify physical and cognitive capabilities, enabling soldiers to perform tasks once deemed to be beyond human limitations. Simultaneously, the integration of artificial intelligence is reshaping battlefield dynamics, offering enhanced decision-making capabilities and operational efficiencies. Together, these advancements are not merely incremental but revolutionary, carrying the potential to redefine combat strategies and geopolitical[2] power structures.

This paper examines the innovation race surrounding human enhancement technologies and its implications for future warfare. It explores the profound ways in which enhanced soldiers and AI-driven systems are altering military capabilities, strategies and the balance of power among nations. Furthermore, it delves into the ethical, operational and geopolitical challenges posed by these advancements, emphasising the need for comprehensive frameworks to navigate this complex and rapidly changing landscape. By analysing these transformative trends, this study seeks to provide a nuanced understanding of the future of warfare in an era of accelerated technological innovation.

The future of warfare is increasingly characterised by technological sophistication, hybrid operations and the integration of autonomous systems. Success on the modern battlefield depends on a nation's ability to adapt to new forms of warfare, cost-effectively leverage advanced technologies and maintain resilient and flexible military structures.

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1 Gormus, Evrim: NATO's Artificial Intelligence Strategy and Interoperability Challenges: The Case of Turkey. JOURNAL OF BALKAN AND NEAR EASTERN STUDIES. 2024. https://doi.org/10.1080/19448953.2024.2414174.

2 Horowitz, Michael/ Schwartz, Joshua: To compete or strategically retreat? The global diffusion of reconnaissance strike. JOURNAL OF PEACE RESEARCH. 2024. https://doi.org/10.1177/00223433241261566.

By developing and proposing a game-theory analytical framework for analysing the military innovation race for future disruptive innovations, this paper is contributing to the assessment of the military implications of actual and upcoming human enhancement innovations.

Establishing the analytical framework for strategic capability development

The impact of human enhancement technologies, both internal and external to the human body, on military operations and tactics is profound and multifaceted. Enhanced soldiers, equipped with advanced physical and cognitive capabilities, can fundamentally alter the nature of warfare. These enhancements include – from a soldier's perspective – increased strength, endurance, speed and agility, allowing soldiers to perform tasks that were previously beyond human capability. From a strategic perspective, this will make military conflicts more complex and more lethal. Enhanced cognitive functions, either internal or external (with artificial intelligence), such as improved memory, faster decision-making and heightened situational awareness, enable soldiers to process information more quickly and accurately, making them more effective in complex and rapidly changing environments.

With these enhancements, traditional combat strategies will be redefined. Enhanced soldiers can carry heavier loads, move more swiftly and operate effectively in extreme conditions, thereby expanding the range of possible military operations. For instance, missions that require prolonged endurance or a rapid response to unexpected threats can be executed with greater efficiency and success. Enhanced cognitive abilities also mean that soldiers can better manage the vast amounts of data generated on the battlefield, leading to more informed and timely decisions. However, it is not clear how humans will cope with the ubiquitarian autonomous systems equipped with tactical and strategic artificial intelligence.

The integration of human enhancements into military units leads to the development of new tactics that leverage these superior capabilities.[3] Small,

[3] Green, Brendan/ Long, Austin: Conceal or Reveal? Managing Clandestine Military Capabilities in Peacetime Competition. INTERNATIONAL SECURITY 44(3), 2019, pp. 48f. https://doi.org/10.1162/ISEC_a_00367.

highly mobile units of enhanced soldiers can conduct operations that would typically require larger forces, increasing operational flexibility and reducing logistical burden. Additionally, the ability to sustain peak performance for extended periods can shift the dynamics of prolonged engagements, providing a strategic advantage in endurance-based conflicts.

Moreover, the psychological impact on both the enhanced soldiers and their adversaries can be significant. Enhanced soldiers might experience heightened morale and confidence, knowing they possess superior abilities. Conversely, adversaries may be intimidated or demoralised when facing opponents who exhibit extraordinary physical and mental capabilities.

Overall, the impact of human enhancement technologies on military operations and tactics involves a comprehensive transformation of how wars are fought. Enhanced physical and cognitive abilities lead to more effective and adaptable combat strategies, creating new opportunities and challenges in modern warfare.

The geopolitical consequences of unequal enhancements are significant and multifaceted, affecting international relations, power dynamics and global security. As nations develop and deploy human enhancement technologies at different rates and levels of sophistication, disparities in military capabilities can lead to shifts in global power balances. Countries with advanced enhancement programmes may gain considerable strategic advantages, potentially leading to new forms of deterrence and coercion. These technological disparities can create an uneven playing field, where technologically superior nations might exert increased influence or control over those less advanced.

In the discussion of military implications of human enhancement research, it is helpful to formalise the military innovation race regarding future disruptive innovations. The following model provides the methodical instruments to discuss this based on strategic formalisation of the situation.

A game-theory model for military innovation race

In this chapter, a game-theory model of an innovation race for military advantage in artificial intelligence (AI) and human enhancement (HE) is developed to provide the instruments for discussing the military implications of

human enhancement innovations. This model is, by necessity, simplified, but it illustrates many of the key strategic features that arise when two rival powers (or groups of powers) compete for technological supremacy. You can expand or adapt these components to reflect more realistic or domain-specific details (e.g. uncertainty[4] in R&D outcomes, multi-stage investment decisions, alliances, etc.).

1. **Assume the following players:**

   - **Player A**: a major power (country or coalition) seeking a military advantage.
   - **Player B**: a rival major power (country or coalition).

   Both players compete in two key technology domains:

   - **AI (Artificial Intelligence)**
   - **HE (Human Enhancement)** which could include biological, genetic or cybernetic augmentations to soldiers or intelligence analysts.

2. **Definition of the strategic setting**

   - Each player can invest resources in R&D of either AI or HE, or potentially split their resources between both.
   - Investments made in each period translate into "technological progress" that accumulates over time.
   - The first player to achieve a technological threshold in either AI or HE could gain a significant military advantage.
   - However, aggressive investment is costly (economically, socially, ethically), and there may also be risks involved (e.g. AI arms-race instability, unforeseen side effects of human enhancement).

[4] Kaplow, Jeffrey/ Gartzke, Erik: The Determinants of Uncertainty in International Relations. INTERNATIONAL STUDIES QUARTERLY 65(2), 2021, pp. 306-319. https://doi.org/10.1093/isq/sqab004.

3. Time structure

We can model the innovation race as a repeated or multi-stage game with discrete time steps t=1,2,…,T in each period:

- **Simultaneous moves**: Both players choose an investment strategy for that period.
- **Outcomes/Updates**: Their technology levels in AI and HE are updated based on the new investments.
- **Payoff realisation**: Partial payoffs (or costs) for that period are realised, but the ultimate advantage may depend on the relative technology levels over time.

For simplicity, we can assume a fixed time horizon T or an indefinite horizon with discount factor $\delta \in (0,1)$.

4. Strategies

Let x_t^A and x_t^B be the fraction of resources (or budget) invested by Player A and B, respectively, in **AI** at time t. Similarly, let y_t^A and y_t^B be the fraction of resources invested in **HE**. For simplicity, assume that each player has a total resource budget normalised to 1 each period:

$$x_t^A + y_t^A \leq 1,\ x_t^B + y_t^B \leq 1$$

(They could also choose to invest less than the total budget if they wish to save or allocate it elsewhere, but typically in an arms race model it is assumed they invest fully.)

A **pure strategy** at time t is then the pair (x_t, y_t). A **mixed strategy** could involve randomising the investment proportions or adding uncertainty.

5. Technology accumulation

Let:

- AI_t^A be Player A's AI capability level at time t.
- HE_t^A be Player A's human enhancement capability level at time t.

Similarly, for Player B: AI_t^B,. HE_t^B.

A simple way to model capability growth is via a production function. For instance:

$$AI_{t+1}^{A}=AI_{t}^{A}+f_{A}(x_{t}^{A}),\ HE_{t+1}^{A}=HE_{t}^{A}+g_{A}(y_{t}^{A})$$

$$AI_{t+1}^{B}=AI_{t}^{B}+f_{B}(x_{t}^{B}),\ HE_{t+1}^{B}=HE_{t}^{B}+g_{B}(y_{t}^{B})$$

where f_A , g_A , f_B and g_B are (usually concave) functions capturing the "return on investment" in each domain. This might be diminishing marginal returns in each period, or more sophisticated functional forms reflecting synergy (e.g. better AI might boost HE research, etc.). For AI and HE it would be realistic to assume exponential increasing returns, which will be discussed later.

6. Payoffs

A common approach to calculate the payoffs is to have a **terminal payoff** at time T that depends on the relative advantage in AI or HE. For instance, we could define:

- If Player A's AI level AI_t^A **exceeds** Player B's AI level AI_t^B by some threshold, Player A gains a significant payoff (military advantage) in the AI domain.
- Similarly, if Player A's HE level HE_t^A exceeds Player B's HE_t^B , Player A gains a payoff in the HE domain.

We can write an example of a terminal payoff for Player A:

$$U_A^{terminal}= \propto *1(AI_t^A\text{-}AI_t^B>\Delta_{AI})+\beta*1(HE_t^A\text{-}HE_t^B)\text{-}C_A$$

where:

- α is the value of achieving AI dominance beyond some threshold Δ_{AI}.
- β is the value of achieving HE dominance beyond some threshold Δ_{HE}.
- C_A represents the total cost of investments or associated risks over time.
- 1 is an indicator function (1 if condition is met, 0 if not).

Likewise for Player B:

$$U_B^{terminal} = \propto *1(AI_t^B - AI_t^A > \Delta_{AI}) + \beta * 1(HE_t^B - HE_t^A) - C_B$$

In some scenarios, **intermediate payoffs** for each period symbolise partial progress or incremental advantages (e.g. improved intelligence-gathering abilities, advanced weaponry). That might be something like:

$$u_A(, x_t^A y_t^A, x_t^B, y_t^B) = R_A(AI_t^A, HE_t^A) - Cost_A(x_t^A, y_t^A)$$

where $R_A(\cdot)$ might capture the short-run benefits of better technology at time t, and $Cost_A(\cdot)$ is the cost of the investments at time t. Then you could use a discounted sum of the period payoffs:

$$U_A = \sum_{t=1}^{T} \delta^{t-1} u_A(x_t^A, y_t^A, x_t^B, y_t^B)$$

The payoff U_A (utility of Player A) in the model encapsulates the military impact of human enhancement by quantifying the strategic advantages derived from surpassing a threshold in human enhancement capabilities relative to the rival, Player B. This utility reflects not only the immediate operational benefits, such as the increased physical and cognitive performance of soldiers, but also the broader strategic leverage gained through dominance in the enhancement domain. By incorporating factors such as the cost of investment, risks and potential synergies with other technologies, U_A offers a comprehensive measure of how advancements in human enhancement translate into tactical measurement for military superiority, deterrence and shifts in geopolitical power dynamics.

Application to disruptive military innovations (HE and AI)

The application of the model to disruptive innovations is intrinsically linked to future military human enhancement innovations as it drives the development and integration of groundbreaking technologies that redefine combat capabilities. Disruptive innovations such as advanced artificial intelligence,

biotechnology and cybernetics create the foundation for enhancing human physical and cognitive abilities, enabling soldiers to outperform traditional limitations. These innovations not only transform individual performance but also influence strategic military doctrines by fostering new operational possibilities and reshaping the balance of power. As military forces increasingly adopt these technologies, the interplay between disruption and enhancement accelerates, setting the stage for a new era of warfare driven by augmented human potential.

For simplicity, only artificial intelligence (AI) and human enhancement (HE) are selected, knowing that these can be exchanged - to some extent – for biotechnology and cybernetics research in the model.

Assumptions for discussion of the ongoing innovation race in HE and AI:

- **AI vs HE allocation**: Each player faces a strategic decision: how to allocate resources between AI and human enhancement. Focusing on one domain might yield dominance there, but ignoring the other could be risky if the opponent invests heavily in it.
- **Arms race and instabilities**: Rapid investment in AI might lead to untested or unsafe systems that pose catastrophic risks (e.g. accidental escalation, loss of control). Similarly, pushing the boundaries in human enhancement might have social or ethical blowback.
- **Spillovers and synergies**: Achievements in AI could accelerate some aspects of HE (e.g. better AI-driven drug discovery). Conversely, breakthroughs in HE (e.g. cognitively enhanced scientists) might speed up AI research. Modellers can introduce coupling between f_A and g_A (or f_B and g_B) to represent synergy or complementary effects.
- **Signalling and information asymmetries**: In many real-world scenarios, players do not perfectly observe the other's investment or progress, leading to incomplete-information games and the possibility of signalling. One might use Bayesian games to model strategic deception or secrecy in R&D.

Application of the strategic toolbox for a simple one-period HE vs AI model:

1. **List of actions**:
    - Each player simultaneously chooses (x,y) with $x+y \leq 1$.
2. **Calculation of possible outcomes**:
    - Final technology: $AI_A=f_A(x_A)$ and $HE_A=g_A(y_A)$; similarly for B.
    - Payoffs:

$$U_A = \propto *1[AI_A\text{-}AI_B>\Delta_{AI}]+\beta*1[HE_A\text{-}HE_B>\Delta_{HE}]\text{-}C_A(x_A,y_A) U_B = \propto *1[AI_B\text{-}AI_A>\Delta_{AI}]+\beta*1[HE_B\text{-}HE_A>\Delta_{HE}]\text{-}C_B(x_B,y_B)$$

Assuming that both players maximise their utility over time, the Nash Equilibrium is the most promising concept:

> **Nash Equilibrium** (in the repeated or dynamic sense): A set of strategies $\{x_t^A, y_t^A, x_t^B, y_t^B\}$ for each period (and for each history of play) such that no player can unilaterally deviate to improve their total expected payoff.

Discussion of the Nash Equilibrium:

- Each player weighs the probability (or indicator) of surpassing the other in AI vs HE, net of their investment costs.
- Typically, you might get a **mixed strategy** equilibrium if neither domain is clearly more valuable or if cost structures are uncertain.
- Or one domain might be more cost-effective and valuable, leading both to heavily invest there, risking a "winner-takes-most" scenario.

Other equilibrium concepts:

- **Subgame Perfect Equilibrium** (in a dynamic game): It is very likely that in real-world AI and HE competition nations' strategies form a Nash Equilibrium in every subgame, ensuring time consistency of strategies.

- **Markov Perfect Equilibrium**: In a dynamic real-world setup with state variables (like $AI_t^A, HE_t^A, AI_t^B, HE_t^B$), a Markov Perfect Equilibrium is where each player's strategy depends only on the current state (not on the full history) in a way that remains a Nash Equilibrium in every state.
- **Stackelberg Equilibrium**: If one player can commit to a strategy first (a leader-follower framework), we might get a Stackelberg model. For instance, if Player A is the global technology leader, they might set a strategy that Player B responds to optimally. It is very likely that the dominant nations take this opportunity.

The extended equilibrium considerations point to practical implications for military capability planning:

1. **Multiple actors**: The strategic analysis needs to be extended from two to multiple players, which allows alliances with other smaller states and corporate actors.
2. **Dynamic signalling and secrecy**: If players hide or misrepresent their technology levels, you can model it as a Bayesian game with incomplete information, focusing on how each side attempts to infer the other's progress and intentions.
3. **Cooperative outcomes**: Players might negotiate arms control or mutual transparency measures to avoid dangerous races, leading to "cooperative equilibria" if enforceable.
4. **Risk aversion and uncertainty**: Incorporating probabilistic R&D outcomes, where large investments do not always guarantee large breakthroughs.
5. **Catastrophic risks or ethical costs**: Adding terms in the payoff function that penalise players for pushing too fast (e.g.,. AI safety concerns, human enhancement side effects).

This game-theory model sketches out the core elements of an innovation race for military advantage in AI and human enhancement. While highly simplified, it illustrates how:

1. **Payoff structures** (military advantage, costs, risks) shape equilibrium strategies.
2. **Dynamic & repeated** considerations (accumulating technology, discounting, potential for negotiation) affect long-term outcomes.

3. **Strategic substitutes/complements** (AI vs HE, synergy effects) complicate investment decisions.

Researchers, defence analysts or policymakers can refine this framework to better reflect real-world details (budgets, uncertainty, espionage, alliances, ethical constraints) and thus help forecast or guide strategic behaviour in emerging military-technology races.

With reference to the military impact of HE and AI research, the arms-race dynamic is notable. When each side fears the other's advantage, both may over-invest, potentially harming both via costs and risk of accidents (a "prisoner's dilemma" dynamic).

The same is true for technological **dominance vs diversification strategies**. If one domain is believed to be more critical, both players might concentrate investments there. Alternatively, each might diversify to hedge against uncertainty. The opposite, yet often used military innovation strategy is **commitment & détente**. In repeated or multi-stage settings, there may be an incentive to form partial agreements or share minimal technology constraints, preventing runaway escalation.

The **risk of an arms race** in human enhancement is a critical concern. As nations strive to outpace each other in developing superior soldiers, this competition can lead to escalating investments in enhancement technologies, diverting resources from other critical areas such as economic development and social welfare. This new arms race can also drive rapid advancements in technology, sometimes at the expense of thorough ethical and safety considerations.

Unequal enhancements as seen in recent times exacerbate global tensions and contribute to regional instability. Nations lagging in enhancement capabilities may feel threatened and seek alliances or develop asymmetric warfare strategies to counterbalance the superior forces of their adversaries. This is already leading to increased militarisation and the potential for conflicts as nations attempt to secure their positions in the global hierarchy.

The geopolitical consequences of unequal enhancements include shifts in global power balances, an increased risk of arms races, heightened global tensions, ethical and political challenges and the need for new international legal frameworks. These factors collectively shape the future landscape of

international relations and global security in a world where human enhancement technologies play a pivotal role.

The integration of human enhancement technologies with conventional military capabilities involves a **multifaceted approach** that aims to create a cohesive and effective fighting force. Enhanced soldiers, equipped with advanced physical and cognitive abilities, can significantly augment traditional military operations.

First, enhanced soldiers can operate synergistically with existing systems such as drones, robotics and cyber warfare tools.[5] For example, soldiers with **enhanced cognitive functions** can process and interpret data from unmanned aerial vehicles (UAVs) more quickly and accurately, allowing for better decision-making and more efficient mission execution. This integration enhances situational awareness and enables real-time adjustments to tactical plans.

Enhanced physical abilities, such as increased strength and endurance, allow soldiers to carry more advanced and heavier equipment, including sophisticated weapons and communication systems. This capability improves the overall operational effectiveness of military units, as soldiers can sustain peak performance for longer periods and in more demanding environments.

Training programmes need to be adapted to ensure that enhanced soldiers can maximise the benefits of their new capabilities. This includes specialised training in the use of advanced equipment and systems, as well as conditioning to seamlessly integrate with non-enhanced soldiers. Cohesion and teamwork[6] remain critical, requiring enhanced soldiers to work effectively within conventional military units.

Logistical support also needs to evolve to accommodate the needs of enhanced soldiers. This includes providing necessary maintenance for cybernetic implants or pharmaceutical supplies to sustain cognitive and physical enhancements. Efficient logistical frameworks ensure that enhanced soldiers remain operationally effective at all times.

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[5] Kostyuk, Nadiya: Allies and diffusion of state military cybercapacity. JOURNAL OF PEACE RESEARCH 61(1), 2024, pp. 44-58. https://doi.org/10.1177/00223433241226559.

[6] Vold, Karina: Human-AI cognitive teaming: using AI to support state-level decision making on the resort to force. AUSTRALIAN JOURNAL OF INTERNATIONAL AFFAIRS 78(2), 2024, pp. 229-236. https://doi.org/10.1080/10357718.2024.2327383.

Ethical and legal considerations play a crucial role in the integration process. Establishing clear guidelines and frameworks is essential to govern the use of enhancement technologies in a manner that respects human rights and adheres to international laws. This involves addressing issues related to consent, the long-term effects of enhancements and the potential for misuse.

Finally, the development of interoperable systems is vital for successful integration. **Military equipment and software need to be compatible with the enhancements soldiers** receive, ensuring seamless communication and coordination during operations. This includes ensuring that enhanced soldiers can interface effectively with command and control systems, enabling them to contribute to strategic and tactical planning processes. Integrating human enhancement technologies with conventional military capabilities involves enhancing synergy with existing systems, adapting training programmes, evolving logistical support, addressing ethical and legal considerations and developing interoperable systems. This comprehensive approach ensures that enhanced soldiers can effectively augment traditional military operations, creating a more capable and responsive military force.

All these elements could be included in the model to bring more realistic results. However, the disadvantage is that the model becomes more complicated and loses the easy-use approach. In a subsequent analytical step, the connection between military domains and disruptive innovations is used to understand the long-term trends in competitive military capability development.

Military domains and disruptive innovations

The development of military domains reflects the evolution of warfare and strategic thinking influenced by technological advancements and changing geopolitical needs. To examine the evolving landscape of military engagement as technological advancements and geopolitical shifts redefine the nature of conflict.

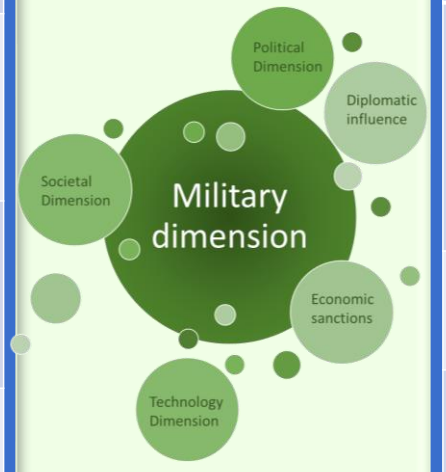
The following figure shows the interdependence and dynamics of military domain concepts and corresponding disruptive innovations, where traditional battle lines blur, and new military domains emerge, when new disruptive innovations change the nature of military tactics.

Figure 1: Historical overview of military domain concepts and corresponding disruptive innovations

Spatially based military Domains

Domain	Disruptive Innovation
Space 1985 US	Rockets, 1942, D Satellites, 1957, UDSSR
Air (world war I)	Air power theory, 1921, IT, Giulio Douhet Strategic Bombing 1921, D, Billy Mitchell Guided rockets, 1950, D/US Nuclear bombs, 1945, US/D Hypersonic weapon, 2018, RU
Navy (Roman Empire)	Maneuverable fleet, 899, UK, Alfred the Great (later Age of Exploration 16th Century) Submarine, 1900, US Torpedos, 1866, UK Unmanned Underwater Vehicle, 1980
Land (Ancient time)	„Understanding the terrain“ , SunTzu, CH, 500 BCE Mountain warfare, Xenophon, EL Tunnel warfare and Cavalry, 500 BCE fire arrows 1232 CH, later rockets Quadcopter, 2000, US, MacCready Drone swarms, 2021, Israel/ CH/US

Hybrid warfare Domains



Grey Zone Operations, Gerasimov doctrine, 2013, RU

Functional based military domain concept

Info Domains

Domain	Disruptive Innovation
Psycho-logy (world war I)	Post Traumatic Stress Disorder (PTSD), WW I Military Deception, 1923, Edward Bernays, A/US Cognitive Psychology 2023, UK
Cognitive domain (not yet)	Alter perception, Affect decision-making, NL, 2023
Infor-mation domain (1953)	Information Operations, US/RU 1953, Influence global affairs, 2010, RU Information superiority, 2010 US

Strategic Domains

Domain	Disruptive Innovation
Strategic planning (Ancient time)	"The Art of War“, Sun Tzu 500 BCE "On War“, 1800, Clausewitz OODA loop, 1990, John Boyd Escalation-dominance, 1960, Herman Kahn Mosaic warfare, 2017
Multi-Domain Operations (2023)	"AirLand Battle" doctrine, 1980, US US Army doctrine in 2023
Infra-structure and protection (Ancient time)	Infrastructure protection, Roman Empire, Integrated protection measures across all domains, 2021, US Including under see cables, 2023, NATO/RU

Electromagnetic Domain (Electronic Warfare)

Source: authors compilation

By exploring a range of historical domain-change scenarios, it became obvious that there are two basic domain concepts. The first and most well-known domain concept builds upon the location within a three-dimensional space. Land, sea, air and space are typically related to the devices required to fight in a specific geographic situation. Historically, warfare was predominantly concentrated on land and at sea. Ancient and medieval conflicts primarily involved large-scale land battles and naval confrontations. Maritime technology's advancement led to powerful navies that were central to empire-building and the control of global trade routes, with European powers like Britain and Spain taking leading roles.

The introduction of the air domain marked a significant shift. The use of aircraft in combat was pioneered during World War I and drastically expanded in World War II. Air power became a critical element of military strategy, enabling rapid and wide-reaching strikes. This era saw the development of strategic bombing concepts and the use of aircraft for reconnaissance and support roles.

The mid-20th century introduced the concept of nuclear warfare, adding a new strategic dimension that emphasised deterrence and escalation control. The Cold War period was characterised by a nuclear arms race and the development of intercontinental ballistic missiles, which brought about the space domain as a critical military and strategic arena.

In recent decades, the information[7] and cyber domains have emerged as vital components of military strategy, reflecting the increasing role of digital technology in society and warfare. Cyber warfare capabilities enable states to conduct espionage, sabotage and influence operations without traditional physical engagement.

Simultaneously, the electromagnetic domain has become more prominent with the advent of advanced electronics and communications technology, highlighting the need to control the electromagnetic spectrum to ensure the effectiveness of sensors, communications and guided weapons systems.

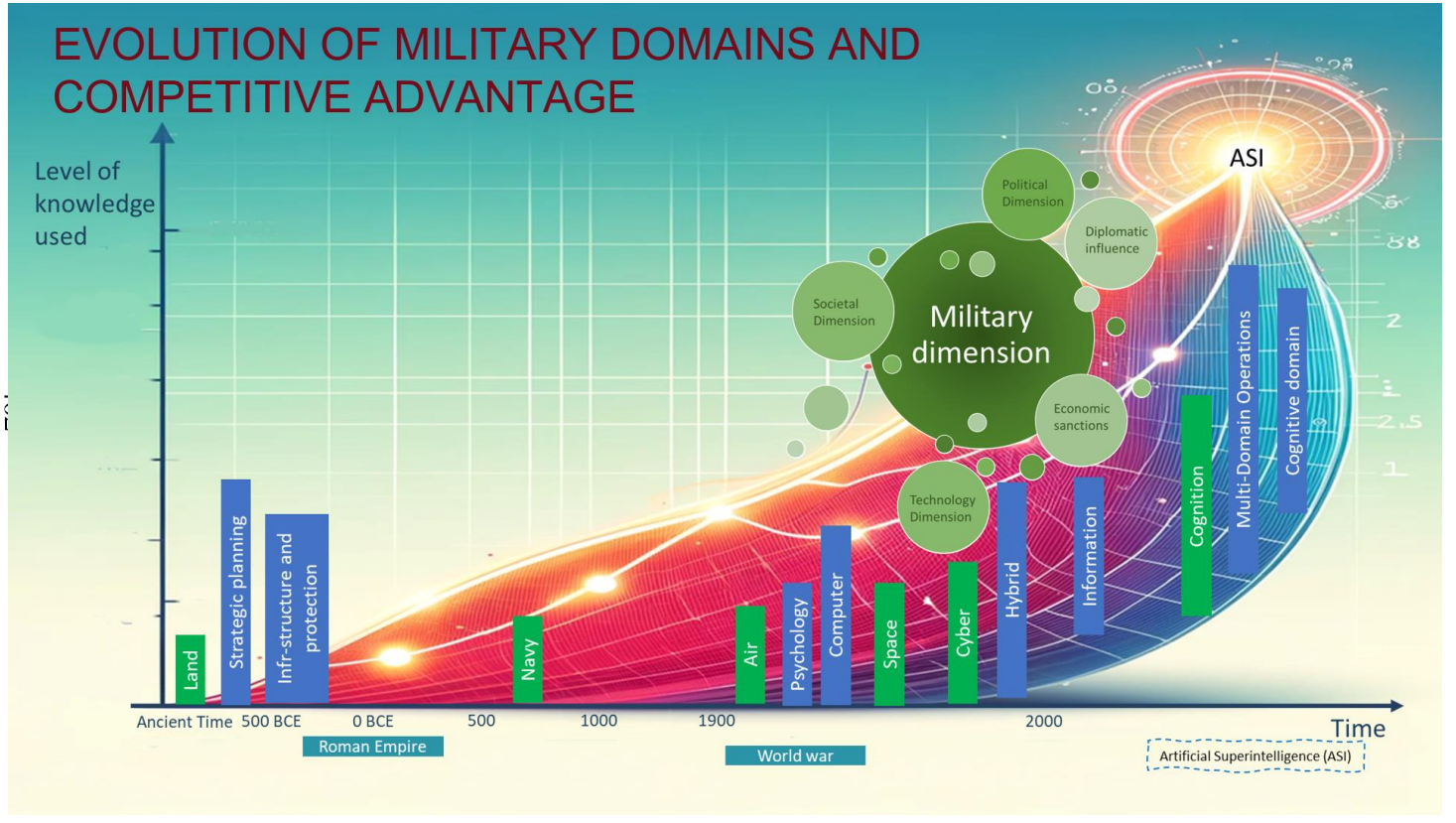
[7] Thayer, Bradley: The political effects of information warfare - Why new military capabilities cause old political dangers. SECURITY STUDIES 10(1), 2000, pp. 43-85.

Today, military strategies increasingly focus on multi-domain operations (MDO), which integrate these disparate elements into cohesive strategies that leverage capabilities across all domains to achieve overwhelming tactical and strategic advantages. This approach is dynamic and continuously adapts to technological advancements and the changing landscape of global power. This approach is inherently knowledge-intensive and requires new approaches to military knowledge management.

The following figure summarises the emergence of military domains over time and their knowledge used. Knowledge is symbolised by number of publications, number of patents, number of communications and data numbers available on the internet. All of these figures are growing exponentially.

Figure 2: See next page.

Figure 2: The evolution of military domains and corresponding knowledge



Source: authors compilation

Besides the emanation of new different military domains following disruptive innovation, which lead to a shift in competitive advantages. Since 2000, the figure shows cyber as the last commonly accepted military domain. However, disruptive innovations in hybrid military tactics, innovations in the information domain and in cognitive capabilities lead us to anticipate that the cognitive domain will be the next commonly accepted military domain.

Human enhancement and other disruptive innovations

There are a large number of new technologies on the horizon. Based on the results from my other contribution,[8] this chapter delves into the dynamic and rapidly evolving field of emerging technologies in the context of transhumanism, which are poised to transform both civilian life and military operations. This chapter explores the latest technology advancements on a higher level and the potential they hold for reshaping military strategies, tactics and overall capabilities. As we stand on the brink of significant technological breakthroughs, it is crucial to understand not only the innovations themselves but also their broader implications. From artificial intelligence and robotics to quantum computing and biotechnology, the technologies discussed here are not just enhancements but are pivotal in driving forward the next generation of military and societal transformations. This chapter aims to provide a comprehensive overview of these developments, assessing both opportunities and challenges that lie ahead.

- **Technological integration (digitalisation)**: embracing advanced technologies such as AI, drones and precision munitions.
- **Cyber and electronic warfare (cyber domain)**: mastery of digital domains to disrupt enemy capabilities.
- **Information dominance (cognitive domain, ASI)**: controlling the narrative and utilising information and automatic reasoning as a weapon. (Complexity and dilemmas beyond human capabilities)
- **Adaptability (nootropics)**: rapidly adjusting strategies and tactics in response to evolving threats.

[8] Klerx, Joachim: The future of human enhancement in the military domain. In chapter TECHNOLOGY in this publication.

- **Integrated defence systems (metaverse)**: protecting assets through multi-layered defence mechanisms.
- **Essential: Human capital, research and material costs**: investing in training and human-machine collaboration to enhance overall effectiveness.

These emerging technologies are created in a never-ending innovation race for the most useful military technologies. Results of the innovation race are new or improved military capabilities which transform into competitive military advantages, which have a number of different strategic implications.

Military implications of human enhancement

Human enhancement research holds profound implications for the future of military operations, promising to revolutionise how wars are fought and won. By augmenting physical, cognitive and emotional capabilities, these advancements empower soldiers to exceed natural limitations, enhancing endurance, decision-making speed and adaptability in dynamic and high-stress environments. These innovations not only redefine individual performance but also reshape broader military strategies, enabling smaller, more agile units to operate with unparalleled precision and efficiency. However, the integration of such technologies also raises critical challenges, including ethical dilemmas, operational dependencies and geopolitical consequences, underscoring the need for careful evaluation and governance in their military application.

Figure 3: Fight regarding the cognitive domain, the different building blocks

Source: Own compilation with symbolic pictures from different internet

The figure illustrates a conceptual framework integrating cutting-edge technologies and human enhancements in military operations, emphasising their synergy, to create effective operational capabilities.

1. **Sensors**: both aerial drones and space-based satellite sensors are shown as critical tools for real-time data collection and situational awareness. These technologies provide comprehensive reconnaissance, surveillance and target acquisition, ensuring that commanders have accurate and up-to-date information about the battlefield environment.
2. **Soldiers with Human-brain interfaces (HBI)**: enhanced soldiers, equipped with advanced gear and potentially nootropics or cybernetic implants, exhibit increased physical endurance, cognitive acuity and adaptability in complex tactical situations. Their ability to process data from multiple sources, including the military metaverse, allows for better decision-making and coordination.
3. **AI (artificial intelligence)**: the central role of AI in this framework is evident, as it analyses vast amounts of sensor data, predicts enemy actions and supports decision-making processes in the command and control centre. AI enhances the speed and accuracy of tactical and strategic planning, reducing human cognitive burdens.
4. **Effector systems**: these include robotic platforms such as humanoid robots and automated weapons systems, which provide logistical support, reconnaissance and direct combat capabilities in high-risk or inaccessible areas. They reduce risk to human soldiers while maintaining operational effectiveness.
5. **Command and control (military metaverse)**: at the core is the military metaverse, a digitally integrated command and control hub that combines data from sensors, AI analysis and human inputs to create a cohesive operational picture. This platform enables real-time strategy formulation, team coordination and the simulation of tactical scenarios, and improves training by providing digital twins of expensive weapon systems.

Together, these components form a multi-domain operational ecosystem where human enhancements, digital technologies and autonomous systems collaborate to maximise efficiency, adaptability and success in complex tactical environments.

Future risks

The adoption of human enhancement technologies and newly identified advancements carries several significant risks that require careful consideration. These risks encompass a wide range of ethical, legal, operational and societal concerns.

One of the primary risks associated with human enhancement technologies[9] is the ethical and moral implications. Enhancing human abilities beyond natural limits raises questions about the fundamental nature of humanity and the potential for creating a societal divide between enhanced and non-enhanced individuals. Issues of consent are paramount; ensuring that individuals fully understand and agree to undergo enhancement procedures is critical. The long-term effects of enhancements, both physical and psychological, are not yet fully understood, posing potential health risks to individuals undergoing these procedures.

Legally, the integration of human enhancement technologies challenges existing frameworks governing warfare and human rights. Current international laws may not adequately address the complexities introduced by enhanced soldiers, necessitating the development of new regulations. There is also the risk of unequal access to enhancement technologies, which could exacerbate global inequalities and lead to geopolitical instability. Countries with advanced enhancement programmes might gain disproportionate power,[10] leading to new forms of coercion and dominance on the international stage.[11]

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[9] Rossiter, Ash: Hyping emerging military technology: probing the causes and consequences of excessive expectations. INTERNATIONAL RELATIONS. 2023. https://doi.org/10.1177/00471178231186256.

[10] Jo, Sam-Sang: Why Change Prevails over Continuity? Critical Junctures, Motivations, Cognitions, and Temporals in Japanese Security Policy Tradition. ASIAN PERSPECTIVE, 2024, 48(4). https://doi.org/10.1353/anp.2024.a944265.

[11] Martill, Benjamin/ Sus, Monika: Winds of change? Neoclassical realism, foreign policy change, and European responses to the Russia-Ukraine War. BRITISH JOURNAL OF POLITICS & INTERNATIONAL RELATIONS. 2024. https://doi.org/10.1177/13691481241280170.

Operationally, the use of human enhancement technologies introduces several risks. Enhanced soldiers may become overly reliant on their augmented capabilities, potentially leading to vulnerabilities if these enhancements are compromised or fail. The integration of these technologies requires significant changes in military training and logistics, which can be complex and costly. Additionally, the potential for cyber-attacks on enhancement systems poses a significant security threat, as adversaries could exploit vulnerabilities to disable or control enhanced soldiers.

Societal impact and ethical implications

The societal impacts of human enhancement technologies are profound, carrying both transformative potential and significant risks. Public perception plays a pivotal role in shaping the adoption of these technologies. Resistance to human enhancement may arise from ethical opposition, fears of unintended consequences or concerns about violating fundamental human values. Such backlash could disrupt military recruitment, lower morale among soldiers and spark societal debates about the acceptability of altering human capabilities for military purposes.[12]

Beyond public sentiment, these technologies threaten to exacerbate economic and social inequalities. Enhanced individuals could outperform non-enhanced individuals in both military and civilian sectors, disrupting labour markets and creating new hierarchies of capability. Such disparities risk fostering economic divides and social tensions, particularly if access to enhancements is restricted by cost, nationality or organisational affiliation.

Emerging technologies, including brain-machine interfaces, genetic modifications and advanced pharmaceuticals, introduce further risks. Brain-machine interfaces, while enhancing cognitive and operational efficiency, could be vulnerable to hacking or misuse, raising concerns about privacy and the potential manipulation of thoughts or actions. Genetic modifications, while offering long-term benefits, might lead to unintended genetic disorders or health complications that extend to future generations. Similarly, advanced

[12] Mello, Patrick: Zeitenwende: German Foreign Policy Change in the Wake of Russia's War Against Ukraine. POLITICS AND GOVERNANCE, Vol. 12. 2024, p. 7346. https://doi.org/10.17645.

pharmaceuticals designed to boost cognitive and physical abilities may have unknown side effects or long-term health consequences, posing risks that remain poorly understood.

The ethical and political challenges surrounding unequal access to these technologies are equally pressing. The unequal distribution of human enhancements could reinforce global inequities, with technologically advanced nations gaining disproportionate power and influence. Enhanced soldiers may become symbols of national superiority, intensifying geopolitical rivalries and deepening divides between countries with varying levels of technological advancement. This inequality raises questions of sovereignty and autonomy, as nations with fewer resources may be pressured into adopting enhancements to maintain strategic parity.

Moreover, the integration of these technologies challenges existing international legal frameworks. Current conventions governing warfare and human rights struggle to account for the blurred lines between soldier and weapon. Enhanced individuals could be considered both combatants and technological assets, creating ambiguities in the application of humanitarian laws. The lack of clear guidelines or enforcement mechanisms risks creating a legal and ethical vacuum that could undermine global security and stability.

In conclusion, while human enhancement technologies hold the promise of revolutionising military capabilities,[13] their societal and ethical implications cannot be overlooked. These include moral dilemmas surrounding the essence of humanity, legal challenges in regulating new forms of warfare, operational risks stemming from technological dependency and broader social disruptions. Addressing these issues requires a comprehensive approach. This includes developing robust ethical guidelines, establishing international legal frameworks, implementing rigorous training and logistics systems and fostering public engagement to ensure informed decision-making and responsible deployment.

[13] Fordham, Benjamin: A very sharp sword - The influence of military capabilities on American decisions to use force. JOURNAL OF CONFLICT RESOLUTION 48(5), 2004, pp. 632-656. https://doi.org/10.1177/0022002704267935.

Key areas for further consideration:

- **Public perception and acceptance**: how to balance public trust with the strategic necessity of enhancements.
- **Potential civilian applications and implications**: the spillover effects of military enhancements on civilian sectors, including healthcare and industry, is non-neglectable.
- **Socioeconomic impacts**: the risk of new divides between enhanced and non-enhanced individuals, both within and across societies, could lead to a social divide.
- **Moral implications of human capability enhancement**: the philosophical questions about altering human nature and creating "superhumans" are particularly relevant to the military sector.
- **Informed consent in the military**: the ethical imperative of ensuring voluntary participation in enhancement programmes is not solved, yet.
- **Equality and accessibility**: the challenge of ensuring fair and equitable access to enhancement technologies to prevent deepening inequalities could be a challenge for society and for soldiers.

By addressing these challenges, societies can strike a balance between harnessing the transformative potential of human enhancement and mitigating the risks to human dignity, global equity and social cohesion.

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