FFI Norwegian Defence
Research Establishment

22/02384

FFI-RAPPORT

The future of military force

– the impact of emerging technologies and defense innovation on state force structures

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Norwegian Defence Research Establishment (FFI) 12. January 2023

Keywords
Trendanalyser
Teknologiske trender
Militær teknologi
Sikkerhetspolitikk
Innovasjon

FFI report
22/02384

Project number
1640

Electronic ISBN
978-82-464-3441-4

Approvers
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Olav Holberg, *Assistant Research Director*

The document is electronically approved and therefore has no handwritten signature.

Summary

Technological change influences military operations. This represents a significant factor in the outcome of military conflicts. State actors therefore invest substantial resources to develop emerging and potentially disruptive technologies (EDT) for military purposes and create operational concepts to exploit these new opportunities. The concepts currently being considered prioritize advanced technologies and network-based solutions that integrate military systems on the battlefield together with AI-assisted data analysis. Many of these ideas have existed since at least the 1990s. The technology now appears mature enough to begin implementing concepts that for decades have been «just around the corner». Understanding the implications of these trends requires envisioning the types of military systems that might be developed with emerging technologies. This report combines an empirical study of the force structures and defense innovation ecosystems of Russia, China, and the United States together with an analysis of these EDT trends to arrive at a notional future force structure for each state.

Many states will have some level of access to most of the relevant technologies, but there are likely to be significant variation in each state's resulting force structure – which can be defined as the combination of elements that produce or sustain combat power (e.g. aircraft, surface vessels, armored vehicles, satellites, or weapons systems). A thorough analysis of Russian, Chinese, and American defense policies revealed variations in the composition of (and the modernization needs within) their current force structures, dissimilarly structured defense industries and defense budgets, inequalities in access to militarily relevant technical knowledge, variations in EDT prioritization, and differences in operational concepts.

The report then outlines how basic combat functions such as mobility, surveillance, communication or fires might be affected by technology over the next three decades. In addition to incremental improvements, some technologies have the potential to create disruptive effects to these functions, in particular autonomous systems, quantum computing, network-based communication and data-sharing solutions, brain-computer interfaces, and manipulation of the electromagnetic spectrum. Combining these assumptions about the future development of EDTs with the current force structures and defense ecosystem idiosyncrasies of Russia, China and the United States allows us to derive a notional future force structures for each of these states.

Such developments can pose challenges as well as opportunities for the Norwegian Armed Forces. Nevertheless, some feasible measures can be taken to create opportunities and minimize the risks – many of which are already underway in some form. Investments can be made to expand and secure digital ICT infrastructure regardless of the exact future force structure composition. Conceptual and technical work to ensure interoperability with NATO allies is another realistic and crucial measure to ensure effective operations in the future. Finally, current and future acquisition projects should emphasize flexibility and "future-proofing" among military systems. Even if the future does not evolve in the manner described in this report, adaptability and flexibility will be useful features for the future that eventually emerges. The future remains unknown, but actively considering potential outcomes such as those offered in this report can contribute to a better prepared, flexible and robust defense policy.

Sammendrag

Teknologisk endring påvirker militære operasjoner. Slik endring utgjør en betydelig faktor i utfallet av militære konflikter. Statlige aktører investerer derfor store ressurser på området. De ønsker å utvikle framvoksende og potensielt disruptive teknologier (EDT) for militære formål. Samtidig vil de utarbeide operasjonelle konsepter for å utnytte disse nye mulighetene. Konseptene som nå vurderes prioriterer avanserte teknologier og nettverksbaserte løsninger som integrerer militære systemer på slagmarken sammen med AI-assistert dataanalyse. Tankene har eksistert siden 1990-tallet. Nå virker teknologiutviklingen moden nok til å kunne implementere konsepter som lenge har vært «rett rundt hjørnet». For å forstå implikasjonene av disse trendene er vi først nødt til å forestille oss hvilke typer militære systemer som kan utvikles ved hjelp av nye teknologier. I denne rapporten kombineres en empirisk studie av styrkestrukturene og økosystemene for forsvarsinnovasjon økosystemene til Russland, Kina og USA med en analyse av EDT-trendene. Sluttresultatet er en tenkt fremtidig styrkestruktur for hver stat.

Mange stater vil ha noe tilgang til de fleste relevante teknologiene. Det vil sannsynligvis være betydelig variasjon i hver stats resulterende styrkestruktur. Denne strukturen kan defineres som kombinasjonen av elementer som produserer eller opprettholder kampkraft. Eksempler kan være fly, overflatefartøyer, pansrede kjøretøy, satellitter eller våpensystemer. En grundig analyse av russisk, kinesisk og amerikansk forsvarspolitikk avdekket variasjoner både i sammensetningen og moderniseringsbehovene innenfor deres nåværende styrkestrukturer. Videre fant vi ulikt strukturert forsvarsindustri og forsvarsbudsjetter, ulikheter i tilgang til militært relevant teknisk kunnskap, variasjoner i EDT-prioritering og forskjeller i operasjonelle konsepter.

Rapporten skisserer hvordan basisfunksjoner som mobilitet, overvåking, kommunikasjon eller ild kan bli påvirket av teknologi i løpet av de neste tre tiårene. Noen teknologier har potensial til å skape disruptive effekter på disse funksjonene. Spesielt gjelder det autonome systemer, kvantedatabehandling, nettverksbaserte kommunikasjons- og datadelingsløsninger, hjerne-datamaskin-grensesnitt og manipulering av det elektromagnetiske spekteret. Vi utlede en teoretisk framtidig styrkestruktur for hver av statene. Det gjør vi ved å kombinere antakelsene om den framtidige utviklingen av EDT-er med de nåværende styrkestrukturene og de forsvarspolitiske særegenhetene i Russland, Kina og USA. Slike utviklinger kan føre til utfordringer så vel som muligheter for Forsvaret. Det finnes noen realistiske og gjennomførbare tiltak for å utnytte mulighetsrom og minimere risikoene. Noen av disse er allerede i gang, i en eller annen form. Det bør investeres i utvidelse og sikring av digital IKT infrastruktur. Det er et nødvendig skritt, uavhengig av den eksakte framtidige sammensetningen av styrkestruktur. Et annet realistisk og avgjørende tiltak for effektive operasjoner i framtiden er konseptuelt og teknisk arbeid for å sikre interoperabilitet med NATO-allierte. Nåværende og framtidige anskaffelsesprosjekter bør legge vekt på fleksibilitet og «future-proofing» blant militære systemer. Selv om framtiden ikke utvikler seg på den måten som er beskrevet i denne rapporten, vil tilpasningsevne og fleksibilitet være nyttig fremover. Framtiden forblir ukjent Likevel kan potensielle utfall, som de som tilbys i denne rapporten, bidra til en bedre forberedt, fleksibel og robust forsvarspolitikk.

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Preface

This report is the product of an ongoing research program at the Norwegian Defence Research Establishment (FFI) known as TEKNO, which explores the likely implications of emerging technologies on future military operations and the Norwegian Armed Forces. Established in 2019, the TEKNO project seeks to leverage the technological expertise found at FFI to conduct what is generally referred to as foresight analysis or futures research. Given the importance of technology to military operations, a key component of foresight analysis is to identify technological trends and attempt to project the pace and direction of further developments.

It is challenging to correctly identify the future evolutional path for any specific technology and even more difficult to anticipate the possible range of applications of a technology. Even so, there is significant analytical value in collecting the disparate trend lines to view them collectively in ways that allow us to anticipate areas of convergence or synergy. Even more valuable is the creation of future narratives or vignettes that take the further step of imagining how technologies might become tangible systems to be used by military forces in the future. By asking basic «*what if*» questions, we can compare the potential consequences of these imagined outcomes against current assumptions, and assess the risks and opportunities that might require course corrections. Our ambition is not to predict the future, but rather to assess likely and potential outcomes based on current observable trends.

This report is the third in a series of analyses that began with a report that methodically examined technology trends and a second that explored how violent non-state actors might utilize future technologies. Forthcoming offerings will combine trend analysis and actor perspectives within the context of a future operating environment as well as assessments that consider the implications of TEKNOs foresight analyses for the Norwegian Armed Forces.

As with any research product, the analytical work contained in this report was made possible with the assistance of many knowledgeable individuals – first and foremost from the contributions of other researchers at FFI. Their insights remain a crucial ingredient to TEKNO’s analytic products and we are extremely grateful for their continued contributions to our efforts.

25 November 2022

Michael Mayer

1 Introduction

For many observers, the 1990-1991 Gulf war was a watershed event. The integration of global satellite navigation, guided munitions, low-observable («stealth») aircraft, advanced radar, and armor-piercing munitions demonstrated a new standard in precision and lethality by American forces as they fully dominated the Iraqi military.[1] The high-tech aspects of that conflict prompted a wave of analysis emphasizing the possibilities and implications of technologically advanced future military operations. Many of the predictions from the mid-1990s are thoroughly familiar to today's analysts and include such themes as distributed network-based military assets, computer-driven data analysis, and autonomous battlefield systems in an «information-centric» environment. Now that these and other technologies finally appear to be maturing, analysts and military leaders alike are predicting fundamental shifts in the character of warfare and dramatic consequences for states that fail to adapt to these changing circumstances (Brose 2019; Freedberg 2021; Ministry of Defence 2017; TRADOC 2019).

Managing the risk stemming from future military technology is an enduring and serious dilemma for defense planners. The potential loss in comparative combat power resulting from a failure to invest in disruptive new capabilities could be severe. On the other hand, the financial burdens of developing ineffectual military systems can be crippling and the price of such missteps are compounded by the opportunity costs that arise when potentially more advantageous alternative projects remain unfunded as a result.[2] Planners must account for future uncertainty even though such assessments are highly complex and often unreliable (Beadle 2016). They have therefore developed tools to cope with the risks associated with this lack of clarity regarding political, economic, social, environmental, and other factors that influence the security environment and future force requirements (Vatne et al. 2020).

One way to investigate the future battlefield is to conceptualize the kinds of technology-enabled military systems that states are likely to wield. The combinations and numbers of elements that produce or sustain combat power such as military aircraft, naval vessels, armored vehicles, weapons systems or personnel are often collectively referred to as a state's *force structure* (Talaber 2021). While a myriad of other aspects of military power such as training, leadership, logistics or intelligence analysis are crucial to the effective use of military force, the physical systems used to accomplish basic functions on the battlefield – mobility, communication, fires, etc. – are fundamental elements of any fighting force. The performance and efficacy of these systems has been greatly influenced by technological innovation, either through incremental improvements or the creation of new ways of accomplishing military tasks (Van Creveld 1991).

This report employs a structured approach to explore the potential effects of emerging and potentially disruptive technologies on state military force structures over the next 30 years. Similar analyses conducted by intelligence services use a combination of sources, but the analysis

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[1] The conflict made a deep impression on the Chinese in particular (Maizland 2020).

[2] This dilemma was exemplified by the debate over US Marine Corps Commandant General David Berger's «Force Design 2030» vision for the service that entailed moving away from the traditional platform-centric structure and a «divest to invest» mantra (Ackerman 2022).

contained in this report is based solely on publically available information. In any case, classified source materials may often have less relevance when looking several decades into the future.

There appears to be a reasonably broad consensus when it comes to identifying which emerging and potentially disruptive technologies (EDT) are most relevant and reasonable (Reding and Eaton 2020). Gauging the effect EDTs might have on new types of military equipment fielded by state actors in operational settings has received less attention. Two important assumptions guide this analysis. First, technology does not impact states equally due to existing force structure elements, defense budgets, and the capacity of domestic defense industries. Second, incremental technological advances are continuously occurring and disruptive technologies are relatively rare. States tend to invest in newer and marginally better equipment to ensure their forces remain effective and survivable, but are likely to be slow to fully embrace truly «gamechanging» technologies until they have been proven to be reliable and paired with operational concepts. Given these two assumptions, any exploration of future military force structures must therefore begin with current force structures, defense innovation ecosystems, emerging doctrinal concepts, and potentially disruptive technologies. Although much of the analysis builds on strong empirical foundations, any attempt to anticipate future developments is highly contextual and prone to error (Hollister 2010; Pernin 2012; Scales 2018). It should be noted that this analysis does not include one important force structure element, namely military personnel. The effects of emerging technology on personnel, including how they interact with new technology and the implications for recruitment and training, are not directly addressed but represent an important set of challenges for defense planners (Fauske and Strand 2022).

The report is divided into four sections. The first section briefly reviews the conceptual linkages between technology and warfare to better understand why states prioritize military innovation and how to analyze the impact that military technological innovation has on warfighting. The second section assesses the innovation potential of three states: Russia, China, and the United States. As three of the largest, most advanced, and most prolific arms-exporting states, these actors exemplify «best-case» innovation scenarios. The analysis for each state includes its current force structure, the defense industry ecosystem and potential for technological innovation, which emerging and potentially disruptive technology areas each state emphasizes, and how emerging warfighting doctrines and organizational changes might allow for the integration of new technologies and systems into the state's operational concepts. The third section explores the effects of emerging technologies on future force structures by reviewing the performance parameters of current systems, assessing which emerging technologies might generate disruptive performance improvements or create new capabilities, and finally imaging how states might combine existing and new systems into a notional future force structure by 2050. These notional future force structures will be used in a later phase to investigate how technology will impact the future operating environment. The fourth and final section explores the implications of these potential future force structures for Norwegian defense planners. If state actors develop force structures similar to those outlined here, what will Norway face in terms of potential threats, interoperability issues with allies, and acquisition choices regarding their future force structure? The future remains unknown, but actively considering potential outcomes such as those offered in this report can contribute to a better-prepared and more flexible defense policy.

2 Technology and warfare: Why states innovate

Technology can be defined as the practical application of science or knowledge for problem solving or the development of new tools such as machines, materials, techniques, or processes (Andås 2020; Reding and Eaton 2020). These advances have historically had a clear and substantial impact on military operations. Technology has expanded our understanding of what encompasses the battlefield as military activities moved from land to the seas, air, outer space, and the cyber domain. New weaponry and new warfighting domains have led to evolving theories of victory, particularly in the nuclear age. Technological advances have influenced various factors from the mobility of personnel and materiel to the range, precision and lethality of munitions. Advances in other areas have also been highly relevant, such as the continuous expansion of medical knowledge and battlefield medicine that increased the survivability of combatants.

We should not assume that technology is the most decisive element in military conflicts, although a focus on technological superiority in warfare has long historical antecedents. This idea is perhaps best represented by J.F.C. Fullers comment in 1919 that «tools or weapons, if only the right ones can be discovered, form ninety-nine percent of victory» (Van Creveld 1991, 225). Technological advantage can ensure tactical victory, but the strategic context for military engagements remains highly relevant. Military conflicts in Vietnam (1955-1975) and Afghanistan (2001-2021) are poignant examples of conflicts in which states wielding vastly superior military technology achieved tactical victories but nevertheless failed to accomplish the strategic-political objectives that originally motivated the conflict. Ukraine's apparent success on the battlefield against Russian forces during 2022 relied on the influx of Western military technology to avoid defeat, but it can also be argued that the core of well-trained Ukrainian personnel and the morale amongst the general population contributed significantly to the country's ability to achieve positive operational outcomes during the conflict (Terrazas 2022).

Many scholars have described the significant role of technology in warfare, although detailed examinations of precisely how technology interacts with other elements of warfare are less plentiful.[3] In a 1989 article, Michael Lind deftly separated military history into three generational periods: a first generation of straight-bore muskets and battlefield tactics of lines and columns, a second generation responding to artillery and indirect fires, and a third post-1918 generation that replaced linear formations with maneuver warfare. Lind's analysis concluded that the two most decisive determinants characterizing the various generations of warfare have been technology and ideas regarding tactics, with the latter category encompassing aspects such as dispersion, logistics, maneuver, and the idea of seeking an adversary's internal collapse rather than their complete destruction (Lind 1989).

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[3] One notable exception is a Norwegian-language contribution by FFI researcher Sverre Diesen, *From technology to strategy and operations – The influence of technological development on military forces and the use of military force* (Diesen 2022).

Assumptions about technology's effects on the outcome of warfare often remain unstated, but can usually be categorized into one of two distinct schools of thought (Biddle 2004).[4] The first views military technology as dyadic in nature – the state with a technological edge over its adversary will prevail in a military conflict. The US Cold War acquisition and force deployment strategy of «offsetting» Soviet numerical superiority in Europe by developing technologically advanced military capabilities – the same technologies that ultimately proved so decisive in 1991 – is an example of this way of thinking. Much of the current rhetoric about technology competitions, such as perceptions of «arms racing» over artificial intelligence and autonomy, is also rooted in this conceptual framing (Hwang and Pascal 2019). The other school of thought relies on systemic explanations, focusing on the particular characteristics of the prevailing «state of the art» at any given time. One prevalent version of this idea is offense-defense theory, which posits that certain military technologies such as tanks or missiles or fortifications favor either offensive or defensive actions. Some observers argue that current trends in military technology appear to favor defensive tactics over the offense, which for Western military doctrine may represent a pivotal historical moment given its general affinity for offensive maneuver (Hammes 2021; Johnson 2022). Understanding technological trends and their implications is therefore highly relevant to understanding how the future of warfare might evolve.

To stay relevant, states actively pursue cutting-edge military capabilities and develop suitable doctrines to leverage these new assets, although organizational resistance to change can often delay such processes. Direct competition to develop technologically advanced military systems played a significant role during the four decade long Cold War between the United States and the Soviet Union. That technology race was characterized predominantly – albeit not exclusively – by national defense innovation within complex military systems such as fighter aircraft, submarines, satellite sensors, and long-range missiles. The renewed focus on great power conflict between the US and China has a similar facet of technology competition. For states seeking to generate effective military power, continuous technological progress, innovation and competition can therefore create what Martin Creveld termed «a treadmill effect in which all countries were compelled to run for fear of standing still» (Van Creveld 1991, 224). Because complex systems require significant time and capital investments, it is advantageous to gaze as far into the future as possible to develop a technologically relevant and modern military force.

Technological innovation in military affairs is not limited to defense industries and products destined for the battlefield. Innovation often occurs in areas with both civilian and military applications. So-called «dual use» technologies include such fields as data processing, artificial intelligence, autonomy, material science, energy production and storage, and biotechnologies.[5] This is admittedly a conceptually muddy area. Civilian technologies developed for the civilian

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[4] For Steven Biddle, technology was one of three fundamental factors evaluated as being potentially decisive for success on the battlefield, the other two being quantitative advantage and force employment. This final factor is the one he ultimately finds most relevant decisive although other scholars have convincingly challenged Biddle's thesis.

[5] Of course, the relevance of civilian innovation is nothing new. Just as military technologies have had widespread civilian applications, so too have civilian innovations long been adapted for military purposes. The stirrup provided a more stable platform for warriors on horseback, the same casting technique for making bells in the 14th century was found to be useful in making cannons, the railroad increased military mobility, the telegraph improved command and control over armies, the internal combustion engine powered aircraft, submarines, and tanks, while the computer vastly expanded information processing.

market such as the Android operating system have found military customers, while the Global Positioning System (GPS) developed and operated by the US military has numerous civilian applications (Gao 2020; Kumar and Moore 2002). Even the collection of technology-based industries located in the Silicon Valley region of northern California that ostensibly epitomize «civilian» technology have deep roots in the defense industry (Blank 2016). Differentiating between the sector in which the technology originates and how the final product is marketed provides a helpful analytical tool. Some products are developed for the commercial market and remain commercial products that are able to be purchased «off the shelf», such as battery technology. Other products like GPS originate in the defense sector, but have civilian applications. Still other technologies are developed and marketed solely for the defense sphere, such as fighter aircraft or tanks. A final category comprises technologies developed in the civilian market but are adapted for use by the military, such as the use of the popular operating system Android in the battle management application Android Tactical Assault Kit (Magnuson 2022).

Although it often lacks clearly defined edges, distinguishing between civilian and military innovation has enduring analytical relevance. The dual-use aspect of technology development can alter the mechanisms by which states ensure access to cutting-edge defense innovation. Basic scientific research occurs within commercial industry and university settings as well as in military research facilities, making civilian-military partnerships even more relevant. Identifying military applications for technologies developed for the civilian market and vice versa also matter because the characteristics of political systems and market structures (for example, a relatively liberal free-market democracy or a managed authoritarian capitalistic economy) may influence the pace and direction of defense innovation within states (Wang, Feng, and Chang 2021; Y. Yang and Liu 2021).[6] Finally, many of the dual-use technologies listed above have fueled significant and sweeping changes in society that some have termed a Fourth Industrial Revolution (Raska 2020b; Schwab 2015). A major shift in military technology came during the 19th century industrial revolution. It is not unreasonable to suspect that a similar phenomenon may once again influence the future battlefield.

2.1 Incremental and disruptive change

New technologies can have direct or indirect effects on warfighting, as many of the aforementioned examples illustrate. It can be analytically useful to distinguish between the technology, the military application of that technology (such as a weapon, platform, or system), the function that application performs, and the doctrine or operational concept guiding its use. The technology underpinning nuclear fission, for example, has several military applications, including nuclear weapons and the nuclear reactors powering naval surface vessels and submarines. These systems, in turn, have specific warfighting functions (long-range fires with nuclear warheads or mobility for naval vessels) as well as doctrinal concepts that guide their use (deterrence postures and warfighting concepts for nuclear weapons, and specific missions such as surface warfare or anti-submarine warfare doctrines for naval vessels). Making explicit

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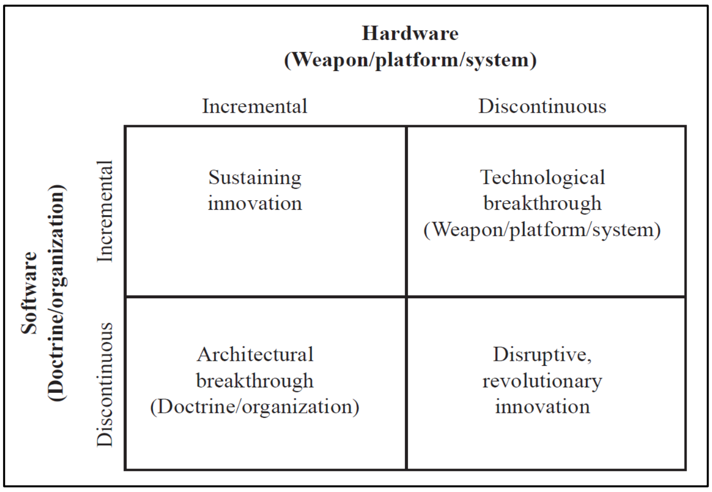
[6] For example, political scientist Francis Fukuyama has argued that the centralized decisionmaking of authoritarian states will ultimately prove inferior to less streamlined but more flexible democratic processes (Fukuyama 2022).

distinctions between technology, application, function, and doctrine helps to understand the relationships between emerging technologies, military innovation, and future force structures. This is true for the specific areas influenced by new technology as well as the areas likely to remain relatively unchanged despite the influx of technology.

Where changes are anticipated, it is useful to evaluate the magnitude of that change, however imprecise such an evaluation might be. We might think of change on a sliding scale or continuum ranging from very little change resulting from emerging technologies, to revolutionary change that alters the fundamental nature or context of military systems, functions, or warfighting itself. As one scholar noted, «[m]ost military innovation is distinctly less than revolutionary or transformational. It consists of incremental, often near-continuous, improvements in existing capabilities» (Ross 2010). One way to understand military innovation is by distinguishing between incremental and discontinuous change across two variables: the «software» of doctrine and organization, and the «hardware» of weapons, platforms and systems. The resulting four combinations provide a useful lens through which we can understand and evaluate military innovation over time.

Incremental change in both software and hardware leads to a situation of *sustaining innovation* with steady improvements to both variables and the minor yet continuous evolution that is most common for the worlds' military forces. Incremental change in software but discontinuous change in hardware, on the other hand, results in a *technological breakthrough* for a weapon, platform, or system – creating something new that can «enable us to do something we didn't know was possible – to fly, to venture into space, to harness the power of the atom» (Ross 2010). If such changes instead occur within doctrinal or organizational aspects of warfighting and changes to hardware remain incremental, an *architectural breakthrough* results that «redefines or reconfigures the way in which the components of technologies, doctrines, or organizations are linked» (Ross 2010). The doctrine of maneuver warfare or jointness may be understood as constituting architectural innovation, whereas the German employment and integration of wireless technology, aircraft, and armor known as «Blitzkrieg» represents an architectural breakthrough. Finally and most dramatically, discontinuous change to both hardware and software results in *disruptive, revolutionary innovation* that renders existing capabilities obsolete and establishes «new, dominant technologies, doctrines, and organizations» (Ross 2010).

This final category is the conceptual equivalent of the much-discussed and often maligned term «revolution in military affairs». Originally conceived by Soviet defense planners who sought a «military-technical revolution» to counter the perceived dominance of Western military systems in a potential European conflict, RMA became an almost obsessive focus of US military strategists and policymakers during the 1990s. After repeated attempts to bring about transformational military technology through concepts such as network-based warfare or effects-based operations, as well as failed acquisition projects such as the US Army's Future Combat Systems, the term fell out of favor by the late 2000s (Raska 2020b; Rodriguez 2014). As a prescriptive concept for defense modernization and future force structure planning, RMA appears to have significant flaws. Blitzkrieg is often cited as a highly disruptive RMA but may not even have been conceived as a disruptive strategy by the Germans (Hobson 2012). However, this only highlights an important distinction between RMA as a prescriptive defense planning framework, as opposed to a descriptive concept that denotes a potent combination of technological and doctrinal elements with the potential to change the character of warfare. It is this descriptive application of RMA that continues to have analytical value.



		Hardware (Weapon/platform/system)	
		Incremental	Discontinuous
Software (Doctrine/organization)	Incremental	Sustaining innovation	Technological breakthrough (Weapon/platform/system)
	Discontinuous	Architectural breakthrough (Doctrine/organization)	Disruptive, revolutionary innovation

Figure 2.1 Conceptualizing military technological innovation. (from Ross 2010).

According to Andrew Krepinevich, a military revolution «occurs when the application of new technologies into a significant number of military systems combines with innovative operational concepts and organizational adaptations in a way that fundamentally alters the character and conduct of conflict» (Krepinevich 1994). As a result, these revolutions alter the «rules of the game» by «radically changing the nature of military competition in peace and war», so that military organizations failing to adapt to the new circumstances often experience a rapid decline (Krepinevich 1994). This is precisely the sort of change anticipated by analysts such as Christian Brose (who argued in 2019 that «militaries that embrace and adapt to [emerging] technologies will dominate those that do not») and Michael Raska, (who has warned that an AI RMA will expose the «limitations of established paradigms in the ways and means of using force») (Brose 2019; Raska 2020b). Such disruptive situations have been an historic rarity. Krepinevich identified between seven and ten military revolutions occurring between the 14th and 20th centuries – three of which occurred nearly simultaneously as the effects of the Industrial Revolution spread to the conduct of warfare.[7] As the term «revolution» has become a somewhat analytically loaded concept, the term *disruptive innovation* or simply *disruption* may be more useful to describe the confluence of discontinuous change for both military technology and doctrine/organization.

As noted above, the vast majority of technological change occurs incrementally, and adoption of military systems using these technologies often occurs even more slowly. Academic arguments debating whether certain technologies are «gamechanging», disruptive, or revolutionary can quickly become mired in definitional disagreements over what those particular terms actual imply. Simplifying the effects of a new technology to undermine claims of a military «revolution» is an

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[7] According to Krepinevich, these include: (1) *Infantry* (14th century: pikemen and archers displaced heavy cavalry); (2) *Artillery* (15th century: gunpower and improved production and design ended defensive dominance in siege warfare); (3) *Sail and Shot* (15th century: from oar-driven galleys to sailing ships with cannon); (4) *Fortress* (16th century: heavy fortifications against cannon); (5) *Gunpowder* (16-17th centuries: improved muskets, infantry weaponry and tactics); (6) *Napoleonic* (early 19th century: standardization in weaponry and logistics, systems, and organization); (7) *Land Warfare* (19th century: after Industrial Revolution, railroads, telegraph, rifling, artillery improvements); (8) *Naval* (19th century: metal hulled steam-powered ships); (9) Interwar Revolutions in *Mechanization, Aviation, and Information* (early 20th century); (10) *Nuclear* (mid-20th century).

effective counter to the often-overenthusiastic promises of technology optimists, but both positions can easily obscure the true impact of technology on military operations. The infusion of technology in the military sphere occurs slowly and unpredictably, but has real effects that alter the battlefield over time. It may be more valuable to identify and understand how a technology can be impactful than attempt to stringently classify it as «disruptive» or «revolutionary». An awareness of which technologies have the potential to be discontinuous and therefore lead to potentially disruptive effects can be very useful, but a definitive contemporary judgement will probably not be possible. With the benefit of hindsight, military historians may be able to conduct a more conclusive analysis, although the contentious debates over conflicts long past suggest that even time may not be the final arbiter.

2.2 Emerging and disruptive technologies in the 21st century

A number of emerging technologies have implications for the types of military capabilities that states are likely to include in their force structures. Many of these technologies are likely to have some influence the future character of warfare, and the combination of technology, doctrine and organization may even lead to disruptive effects. Technology trend studies published over the past five years are remarkably consistent in their estimations regarding the relevance of certain technology areas for future military operations (Andås 2020; Reding and Eaton 2020; United States Training and Doctrine Command (TRADOC) 2018).

- *Digital technologies* including offensive and defensive cyber capabilities, advanced analytics and big data (AABD), augmented and virtual reality (AR and VR), blockchain technology, digital twins, wireless data communication infrastructure such as 5G networks, and the Internet of Military Things (IoMT) are becoming the backbone enabling military systems to function or process information.

- *Artificial intelligence* and the subset of AI that includes the various forms of machine learning algorithms continue to develop amid oversized expectations regarding their potential applications. The near-term uses of AI will enable rapid processing and analysis of intelligence and/or sensor data as well as enable decisonmaking abilities for robotic systems.

- *Autonomy* for unmanned platforms, robotic systems, and weapons such as cruise missiles and loitering munitions has already become an important warfighting capability, and new generations of autonomous systems are likely to incorporate more advanced algorithmic decisionmaking to allow true human-machine teaming.

- *New materials and manufacturing processes* from graphene/carbon nanotubes to additive manufacturing will enable new lightweight materials, energy generation and storage, rapid prototype construction and the production of spare parts in the field or aboard ships.

- *Ubiquitous sensing* that leverages advances in nanotechnology, wireless communication, enhanced data processing, and new materials will reduce the cost and size of various sensors and therefore significantly increase the number of sensors deployed in all domains, with AI providing data analysis on the massive amount of information generated.

- *Biotechnology and human enhancement* is a rapidly developing commercial industry that includes biomedical technology, synthetic biology (genetic engineering, bio-manufacturing, etc), and human augmentation through exo-skeletons, neuro-electronics or genetic modification.

- *Electromagnetic manipulation* is hardly new, but advances in sensor technology and AI will likely enable new possibilities and threats within the electromagnetic spectrum, particularly regarding network communication and interference, as well as signature management.

- *Quantum technologies* are a much-discussed group of technologies that utilize the strange properties of quantum mechanics, ranging from quantum communication, sensing and radar systems, computing, and precision navigation and timing.

- *Hypersonic vehicles* able to operate at speeds exceeding Mach 5 (6125 kph) are being developed, including cruise missiles (HCM), rocket launched hypersonic glide vehicles (HGV), and reusable hypersonic aircraft.

- *Space technologies* including various types of satellite sensors and space vehicles are becoming more prevalent as size, weight and power requirements shrink for most types of satellite sensors and an increasing number of commercial actors enter the domain.

More detailed descriptions of these technologies and their potential impact can be found in other publications, but this brief review of the most technology areas is provided simply as a reference.

3 State innovation and technology development

State actors invest in research and development activities intended to develop new militarily relevant systems for use on the battlefield. These innovation efforts can take various forms, including «top-down» initiatives that coordinate state-level decisionmaking with government-funded research and defense industry contracts at the national level, innovation emanating from within the service branches, or tactical innovation driven by emerging requirements during conflicts (Barno and Bensahel 2020; Grissom 2006; Raska 2020a). Decisionmakers tend to approach defense innovation as part of a strategic competition to field effective military systems able to operate at levels comparable to their potential adversaries. The level of technology at any given time creates a threshold under which many systems are non-competitive. The treadmill metaphor – in which a lack of innovation and modernization does not equate to maintaining the status quo, but rather falling behind – is therefore quite apt. Even small states that are unable to match the quantitative superiority of a potential adversary will nevertheless be compelled to invest in sufficiently advanced military equipment to make that investment meaningful.[8]

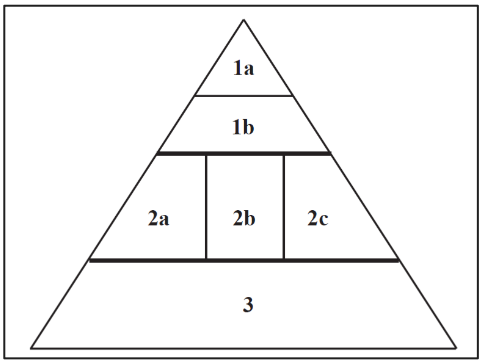

Figure 3.1 Hierarchy of global arms producers.

According to one analysis, the United States is the sole Tier 1a country, while the UK, France, Germany and Italy (and possibly Russia and China) comprise Tier 1b. The next tier (2a) contains states with advanced but quantitatively limited arms production such as Australia, Canada, Israel, and Norway. Tier 2b states have modest yet expanding arms industries (Argentina, Brazil, Indonesia, Iran, South Korea, Turkey). Tier 2c states such as India have sizeable production with limited ability to produce highly sophisticated systems. Tier 3 states (Egypt, Mexico, Nigeria, etc) have limited and low tech arms production. From Bitzinger et al. 2011.

To understand the capacity and direction of state military technological innovation, four factors will chart each state's path towards a possible future force structure: current force structure, defense innovation ecosystem, technology prioritization, and doctrinal and organizational adaptations.[9] A state's *current force structure* will be the starting point, as military innovation and modernization does not occur in a vacuum. Each state's current force structure elements – including everything from aircraft, long-range missiles, surface vessels and submarines, tanks and other armored vehicles, air defense systems, and electromagnetic warfare elements – provide a baseline onto which new technologies and systems will either be integrated or used to replace older, less capable elements.[10] The general structures and trends in each state's *defense innovation ecosystem* – including budgets, research and development efforts, military-civilian industry cooperation, and

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[8] Given the limited defense budgets of smaller states, the high cost of military equipment limits the number of systems acquired to levels below the requirements for adequate combat power, the so-called «marginal defense problem» (Diesen 2020, 266).

[9] This framework is based on (Bitzinger et al. 2011; Klungtveit 2021; Raska 2020a).

[10] A related concept is that of «technology debt», a metaphor originally popularized by software engineer Steve McConnell in 2007 to capture the idea that avoiding technological investments in the present leads to the accumulation of a «debt» for which solutions can be far more expensive when finally addressed (McConnell 2008).

human capital – offer insights into the state's ability to conduct and sustain innovation, particularly important when states are less willing to transfer their advanced military technology.[11] Large investments in developing every emerging technology are usually not possible and even large states must prioritize. Insights into each actor's emerging *technology prioritization* can provide some sense of the direction innovation efforts are heading, whether it be artificial intelligence, biotechnology or digital/cyber capabilities. Finally, each section includes an evaluation of state efforts to develop new *doctrinal and organizational adaptations* to best utilize emerging technologies. These observations provide some sense of how effectively the future force will operate with new technologies.

The following sections contain this four-part evaluation for Russia, China, and the US to assess military innovation efforts currently underway as well as the potential for future innovation. These three states are among the largest, most capable and most influential defense innovators: Russia (19 percent) and the United States (39 percent) have accounted for nearly 60 percent of global arms sales over the past five years, with China in fourth place (4.6 percent) (Wezeman, Kuimova, and Wezeman 2022). The evolution of their defense industrial bases and future force structures will therefore be highly influential.

3.1 Russia

Russia's invasion of Ukraine in 2022 cast a shadow of uncertainty on its future innovation efforts due to the massive equipment and personnel losses sustained during the fighting, the economic instability resulting from sanctions, and the domestic and international political consequences of the conflict. These uncertainties make it nearly impossible to predict the pace, scope and direction of the country's military modernization over the next 30 years. The Russian military may field a robust force structure in 2050, but the path leading to that particular outcome has been altered by recent events. Prior to the Ukraine invasion, Russia pursued a substantial program of military modernization despite underlying budgetary pressures. The previous State Armament Program (GPV 2020) in effect from 2011-2020, emphasized modernization of the Navy and Aerospace Force along with increased military readiness and professionalism across its armed forces.

Military expenditures rose during the first years of GPV 2020, but declined after 2016. This downward trend was to be reversed in the new GPV 2027 approved in 2018, and even with the reductions proposed by the Russian Ministry of Finance in 2020 defense expenditures remain close to US$60 billion annually and constitute roughly four percent of GDP (Perrin 2020, 7). Russia remains one of the world's largest and more capable militaries, with the fourth highest defense spending globally (behind the United States, China, and India) when adjusted for purchasing power parity (Robertson 2021). Spending projections through 2030, given assumptions of slow to medium economic growth (between 1.5 and 3 percent) along with defense spending remaining near four percent GDP, implies a spending increase of 20 and 40 percent

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[11] A recent Norwegian language source details Norway's defense innovation ecosystem. See (Bjørk et al. 2022).

(Oxenstierna et al. 2019, 110). These projections may now be overly optimistic, as the conflict in Ukraine appears to have severely impacted the Russian economy (Sendstad and Udal 2022).

3.1.1 Current force structure

Gauging the size and modernization status of current Russian forces has become even more problematic given the equipment losses from the Russian invasion of Ukraine. This overview is therefore far from exhaustive, but is intended to provide a rough starting point for analysis. *Ground forces* total some 350.000 and are comprised of regular Army units organized in a mixture of divisions and brigades, Airborne/Air Assault VDV units, and elite special operations forces (A. S. Bowen 2020). In 2019, Russian ground forces fielded 2750 main battle tanks (MBT) and approximately 10000 armored fighting vehicles, the vast majority of which are older yet modernized equipment. Russia planned to produce several thousand new T-14 Armada MBTs reportedly costing upwards of US$3.5 million each, although production has been severely delayed (Gady 2015; Suciu 2022). A similar situation exists for self-propelled artillery and multiple launch rocket systems (MLRS), with new units added over the past decade comprising less than 20% of total systems (A. S. Bowen 2020; Oxenstierna et al. 2019, 121–24).

Russia made significant investments in air defense capabilities during GPV 2020, including acquisition of the long-range S-400 system and over 100 short- and medium-range systems, primarily the Pantsir-S1/S2 systems offering protection against aircraft, helicopters, precision munitions, cruise missiles and UAVs. Over 90 percent of the tactical air defense battalions added since 2011 are equipped with new systems, soon to be augmented with the new S-500 system currently undergoing testing. Electromagnetic warfare (EW) capabilities have been prioritized as a means of undermining NATOs perceived dominance of the electromagnetic spectrum and disrupting the West's reliance on it as well. Most notably, the Moskva-1 system gathers intelligence, conducts jamming and signal suppression while the Krashukha-2 is able to jam an adversary's radar and generate false targets to mislead enemy aircraft (Perrin 2020, 13).

Russian *Aerospace Forces* (including the Air Force, strategic Air Defenses, and Space Forces) enjoyed a prioritized status during GPV 2020 implementation, with particular upgrades and improvements to missile and precision munitions (A. S. Bowen 2020). The Russian air force operates predominately 4th generation Soviet-era design aircraft that have been upgraded and modernized – the Sukhoi Su-35S is considered to be a highly capable 4++ generation fighter/attack aircraft. Development of the 5th generation Su-57 fighter is delayed and will likely not enter service until later in the GPV 2027 program period. Russia has a limited long-range heavy air transport capability in addition to persistent deficiencies in early warning sensors and mid-air refueling capabilities (A. S. Bowen 2020). As has been the case with other acquisitions, helicopter production suffered after losing a cooperative relationship with a Ukrainian engine manufacturer in the wake of the 2014 Russian annexation of Crimea. Modernization of attack and transport helicopters will ostensibly proceed with a Russian supplier, as will renewal of the approximately thirty heavy transport helicopters. According to one estimate, about half of all fixed wing aircraft and nearly 85 percent of the helicopter fleet acquired since 2011 are newer models rather than modernized versions of older equipment (Oxenstierna et al. 2019, 121–26).

The *Russian Navy* received significant investments during GPV 2020 for the acquisition of over 24 modern submarines and approximately 50 surface vessels. The shipbuilding plan, which experienced some delays, has emphasized smaller vessels with modular designs oriented towards coastal defense such as frigates, corvettes, and missile ships that are equipped with anti-ship and land-attack cruise missiles. This includes the Kalibr cruise missile as well as the Zircon ship-launched hypersonic cruise missile under development that boasts a range of nearly 1000 km. Both systems are deployable on surface vessels as well as submarines (Perrin 2020, 7–8). The larger bluewater vessels in the Russian Navy, including its sole aircraft carrier, are ageing Soviet-era vessels entering their fourth decade of service through refits and life-extension upgrades.[12] This situation is not expected to change in the near term, as Russian shipbuilders continue to struggle with deliveries. Since 2011, however, nearly all the nuclear-powered (SSN/SSGN) and diesel-electric submarines have been either replaced or refurbished (Oxenstierna et al. 2019, 123–25). The Navy therefore relies heavily on its frigates and submarines, and its operational capabilities are focused mostly on sea denial and littoral defense (A. S. Bowen 2020).

Protecting the submarine component of Russian *Strategic Forces* remains one of the Navy's primary missions as well (A. S. Bowen 2020). The Navy is transitioning to the new Borai-class SSBN armed with the recently developed solid fuel Bulava SLBM. The nine SSBNs in operation at the end of 2019 are to be supplemented by an additional 11 submarines by 2030. The primary platform for the air component of Russia's nuclear forces remains the Soviet-era four-engine turboprop Tu-95 Bear, with roughly 75 percent having received radar and avionics upgrades over the past decade in part to accommodate a new nuclear cruise missile (Kh-102) (Oxenstierna et al. 2019, 123–27). Russia has prioritized land-based systems over the sea and air components, however, funding a modernization program to replace older ICBM forces systems with stationary and mobile variants of the RS-24 *Yars* and RS-28 *Sarmat*, along with the hypersonic boost-glide nuclear capable Avangard system under development (Oxenstierna et al. 2019, 126; Perrin 2020, 11).

Russian *Cyber forces* are, according to an analysis by IISS, led primarily by the Main Directorate of the General Staff of the Armed Forces (known colloquially as the GRU). Additionally, each military district has a cyber-security center, and other agencies such as Federal Security Service (FSB) and the Foreign Intelligence Service (SVR) also carry out cyber operations. Russia views its cyber capabilities in the broader context of information operations, with a particular emphasis on intelligence, surveillance, and reconnaissance (ISR) efforts as well as producing a range of «effects» in the cyber domain (IISS 2022). State-sponsored groups have been among the most active in cyberspace, with dozens of attributed operations over the past five years alone (CFR 2022). Among these are well known advanced persistent threats (APT) such as the group *Fancy Bear* which, along with the GRU's 85th Main Special Services Center, have been linked to the 2020 cyberattacks on the Norwegian and German parliaments (RFE/RL 2020).

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[12] According to a RAND report, «the aircraft carrier Admiral Kuznetsov took part in Russia's operations in Syria. The carrier hosted only 15 aircraft, two of which crashed when attempting to return to the ship» (Crane, Oliker, and Nichiporuk 2019, 40).

In sum, Russia's force structure underwent a significant modernization effort over the past decade, particularly regarding submarines, smaller surface vessels, long-range stand-off weaponry and strategic missile systems. Significant and growing gaps remain, however. As Oxenstierna et al. concludes, «delays, cost overruns, budget constraints, and – most importantly – the sheer volume of Soviet-made equipment to turn over imply that during the next decade the bulk of Russia's military equipment will still consist of modernized and refurbished gap-filling legacy platforms and systems» (Oxenstierna et al. 2019, 127). The effects of the 2022 Russian invasion of Ukraine on Russia's near-term force structure size and composition remain unclear, although substantial numbers of main battle tanks, armored vehicles, aircraft, and missiles have been destroyed or expended during the fighting (Roblin 2022).

3.1.2 Defense innovation ecosystem

Russia has a substantial defense industry that ranked second in terms of global military exports between 2016 and 2020, exporting to 45 states and comprising roughly 20 percent of all global arms sales (A. Bowen 2021, 8). Even with this formidable industrial base, Russia's capacity to successfully pursue innovation of emerging military technologies may depend on a number of additional factors, including research and development budgets, levels of technological self-sufficiency, access to scientific and engineering expertise (also known as «human capital»), civilian-military cooperation, and diversification in procurement. Russia's scores across these measurements are variable but generally reflect a weaker innovation base for developing and producing future military technologies, compared with the United States and China. One apparent weakness is the production of microchips and other electronics. Evidence of Russian dependence on foreign technology was revealed on the battlefield in Ukraine as reports emerged of military systems utilizing computer chips from household appliances (Whalen 2022b, 2022a). The subsequent sanctions regime has only exacerbated the problem (Miller 2022).

Government funding for applied military research and development has since 2014 tended to fluctuate between 9.5 percent and 12.5 percent of the total defense budget. In this context, applied research represents R & D devoted to a practical aim or outcome. This is in contrast to basic experimental or theoretical research that explores the theoretical concepts underpinning a technology without any particular application in mind. When combined with government spending on civilian research and development, applied military R & D is roughly one third of the total research and development budget. This is considerably more than the United Kingdom (16 percent) or Germany (under 3 percent), but less than the United States (50 percent) (Engvall 2021, 12,15-16).

The majority (80%) of defense industry producers in Russia are nationally owned and controlled though Rostec, a state-owned holding company founded in 2007. Research institutions, «design bureaus», and «scientific production associations» make up the other elements of the Russian defense sector, reflecting an organizational structure with long historic roots from the Soviet Union. The approximately 300 research institutions – responsible for generating the ideas and concepts for military use – experienced economic stagnation and loss of expertise during the late 1990s and early 2000s, but has rebounded in the past decade. Design bureaus during the Soviet era functioned as the bridge between the concepts developed in research institutions and the production facilities, creating prototypes that could then be mass-produced. They retain a somewhat similar function today as commercial entities that develop military projects. The final category, «scientific production associations», were created during the 1960s in an attempt to establish a seamless administration from the R & D phase to final production, but today are often difficult to distinguish from research bureaus (Engvall 2021, 17–22). Two final entities worth noting are the Advanced Research Foundation (ARF), an entity created in 2012 and modelled after DARPA in the United States, and the Era technology campus established in 2018 on the Black Sea. These two innovation centers – Era in particular with regard to military applications – focus on next-generation weaponry such as AI, robotics, autonomous systems, superconductors, and additive manufacturing (Oxenstierna et al. 2019, 117; Zysk 2021a, 15). Russia's microchip industry lagged behind industry leaders for decades, and their recent limited investments in modern lithographic machines are a necessary but not sufficient step for advanced microprocessor production (Bryen 2022; Tyson 2022).

Since many promising emerging technologies for military applications are strongly driven by advances in the civilian commercial sector, the degree of cooperation between civilian and military research entities is a highly relevant factor. It appears as though military innovation occurs primarily through state-run institutions, and that large privately-held technology firms struggle to secure private capital for innovative research in areas such as artificial intelligence (Edmunds et al. 2021, 67–68). With state-centric top-down organization, competition between companies to develop innovative solutions is reduced, as are technology transfers and «spill-over» from the civilian sector to applied military research (Bukkvoll, Malmlöf, and Makienko 2017; Edmunds et al. 2021). Some efforts have been made to counteract this trend, with the Era technology campus constituting one prominent example.

The organizational R & D structures and financial investments suggest some support for defense innovation, although the defense industry itself has had inconsistent results. Educational trends within Russia are not conducive to producing highly skilled technicians, labor productivity is low, corruption is rampant, and weak intellectual property rights undermine innovation (Zysk 2021a, 20). The shortage of «human capital» is a persistent concern, as the lack of civilian innovation opportunities and funding, the low educational standards and lower standards of living led many skilled workers to leave Russia for better conditions and salary elsewhere. This «brain drain» has slowed in recent years, although conditions are not yet optimal for cultivating and attracting talent (Klungtveit 2021). Negative demographic trends are likely to exacerbate this and other problems for the Russian economy and military (Goble 2022).

Summarizing the challenges of developing new military technologies and successfully producing existing designs, one analyst concluded that:

> Russia's defense industry is capable of producing advanced systems across most weapons categories. At the same time, some sectors of Russia's defense industry struggle with slow production, limited production capacity, and quality control issues. Since 2011, and amid a massive state armaments program, the defense industry has produced, deployed, and upgraded numerous systems under design since the 1990s, but it still struggles to produce wholly new designs. Production of

> new Russian designs face cost overruns, design flaws, and failure to produce on time, issues that also apply to other countries' defense industries (A. Bowen 2021, 2).

3.1.3 Emerging technology priorities

Political support for defense innovation, expressed in official documents or speeches by individuals in leadership positions, can be influential in driving innovation processes forward. Russian president Vladimir Putin has voiced support for the defense industry, remarking in 2015 that it should be "one of the main locomotives for innovation" and "set the bar for technological and industrial development" (Bukkvoll, Malmlöf, and Makienko 2017). The Russian president has also indicated a strong interest in emerging technologies and their strategic implications. In what is now a well-known quotation, Putin stated in September 2017 that «artificial intelligence is the future, not only of Russia, but of all of mankind ... Whoever becomes the leader in this sphere will become the ruler of the world» (Gigova 2017). Less than a year later in an address to the Russian Federal Assembly, he highlighted the development of five new nuclear-capable weapons systems, including several new missile types of ballistic, cruise and hypersonic systems, along with a high-speed nuclear-powered unmanned underwater vehicle ostensibly capable of carrying a nuclear warhead at speeds up to 70 knots (Connolly 2021).

These statements illustrate a desire and motivation to capitalize on both existing and emerging technologies in future conflicts. Over the past decade, Russian defense research and development efforts have focused on a number of potentially disruptive military technologies. In addition to AI, research areas include big data, quantum computing, autonomy and robotics, automated decisionmaking, materials technology and additive manufacturing, hypersonics, and space technologies. Furthermore, scientists have explored so-called 'weapons based on new physical principles' – a category that includes electromagnetic manipulation for directed energy, electromagnetic pulse weapons, and creating bioweapons through genetic engineering (Kofman et al. 2021; Zysk 2021b).

Russian military analysts often divide the technological evolution of warfare into six generations (steel arms; gunpowder and smoothbore weapons; rifled high capacity weaponry; automatic weapons/tanks/aviation; nuclear weapons; PGM and space) (Kofman et al. 2021, 10). Accordingly, a seventh generation referred to as the autonomous revolution will likely incorporate many of the technologies mentioned above. At its core, one analyst summarized, this new generation of warfare is the combination of machines and computers: «autonomous weapons, swarms of robotic vehicles in multiple domains, self-organizing defensive systems, automated weapons, big data analytics and machine- and deep-learning programs are at the heart of a potential far reaching alteration of how future wars will be conducted» (Engvall 2021, 31). ARF's deputy general Vitaly Davydov argued in 2020 that the mass use of military robotics may be inevitable when autonomous systems are able to act more quickly, accurately, and selectively than humans on the battlefield (Bendett 2021, 48).

The projects under development at research entities such as Era and ARF reflect this prioritization. At ARF, artificial intelligence has received particular emphasis along with UGVs and other autonomous systems such as a deep submergence UUV, superconductors, and ultra-thin materials for improving camouflage and protection (Zysk 2021b). At the Era technology campus, R & D is organized into 14 prioritized sectors, including AI, robotics, various IT programs, biotechnology, and ‘weapons based on new physical principles’. Research efforts and military innovation in these areas is being coordinated by the Defense Ministry’s Main Directorate of Research and Technological Support of Advanced Technologies (or GUNID), drawing on university and research institutions, engineering centers, and defense industries (Zysk 2021b). The Russian space agency *Roscosmos* has ambitious plans including the construction of a new space station and a cooperative project to build a moon base together with China, but technology access and budgetary problems may limit these activities (Koren 2022).

3.1.4 Doctrinal and organizational adaptations

Analyzing open-source writings by Russian military strategists and theoreticians provides a useful, albeit limited, view into the doctrinal thinking in Russia about modern warfare and the use of emerging technologies. In general, the basic elements of the «Russian way of war» are easily adapted to emerging technologies. The country’s «active defense» approach emphasizes defensive maneuver, an approach «premised on defeating and degrading an opponent while buying time and preserving forces, at the expense of territory», with the expectation that the battlefield will be fragmented without a «contiguous front» or concentrations of forces (Kofman et al. 2021, 14–15). Elements such as kinetic long-range fires with precision-guided munitions, and/or informational and electromagnetic warfare (EW) to degrade an opponent’s organization and forces, may be followed up by highly mobile vehicles to engage an adversary with direct fire (Boston and Massicot 2017, 2; Kofman et al. 2021, 15). Although Western analysts have referred to some of these elements as anti-access and area denial (A2/AD) capabilities, these concepts do not actually appear in Russian military writings. High-ranking military officers such as Valery Gerasimov argue more broadly that Russian armed forces must be «ready to conduct new-type wars and armed conflicts» that integrate emerging technology and new arenas such as the information space, using both kinetic and non-kinetic means (Kofman et al. 2021).

Russia views itself as a great power yet weaker than its high-tech rivals, and is therefore reliant on identifying and fielding effective technological countermeasures and asymmetric responses. Developing unmanned systems, ISR capabilities and EW assets «combine to make the battlefield more visible and controllable and allow Russian forces to mass fires quickly and effectively» (Konaev 2021, 65). As Margarita Konaev notes, «Russia’s investments in new technologies also aims to enable a successful confrontation via non-military means during crisis, establishing information superiority over the adversary during the initial period of war» (Konaev 2021, 66). Russian military thinking does not appear to have shifted substantially, but rather integrates new technologies into existing doctrines, particularly regarding influence operations (Zysk 2021a). Not surprisingly, a significant portion of Russian doctrinal focus remains on the United States and its military forces and doctrines, including possible counters to concepts such as distributed multi-domain operations. Some Russian strategists argue for investments in new technologies and weapons that exploit the vulnerabilities arising from an adversary that relies heavily on a complex command and control system. Whereas defeating an adversary might previously have relied exclusively on fires, a more comprehensive approach that integrates informational and electromagnetic warfare could enable not the physical but the «functional defeat of the enemy» (Kofman et al. 2021, 25).

Russia's armed forces have demonstrated a willingness to experiment with new technologies in operational settings and create new operational concepts that leverage the unique features of some of these high tech systems. The country's military involvement in Syria and Ukraine provided an opportunity to develop new equipment, tactics and operational frameworks, particularly regarding the use of unmanned systems and electromagnetic warfare (Åtland et al. 2016). In July 2014, Russian forces utilized tactical UAS to provide targeting information for artillery units, destroying elements of four Ukrainian army brigades (Konaev 2021, 73). New EW units formed in 2009 can specifically exploit the ability to manipulate the electromagnetic spectrum to disrupt an adversary's ability to operate while protecting one's own forces from attack (Kjellèn 2018). These doctrinal ambitions appear to have been less successful during the 2022 invasion of Ukraine despite the presence of three Russian EW brigades, partially due to Ukraine's use of US-supplied EW assets (B. Clark 2022).

In sum, Russia's force structure was fairly modernized prior to March 2022, particularly regarding missile systems, fighter aircraft, electromagnetic warfare units, smaller surface vessels, and submarines. However, the Russian military will now face increased budgetary pressures and vulnerabilities in its defense industry that may hinder its ability to develop and field new systems that radically alter the existing force structure. Currently, Russian innovation efforts focus on autonomy, electromagnetic manipulation, materials technology, and biotechnology – areas that appear to correspond well with the «Russian way of war» emphasizing long-range fires, EW, disruption of adversary C2, and non-kinetic means of warfare. Russia has demonstrated a willingness to experiment, adapt, and innovate with new technologies, as well as create new organizational structures to leverage the opportunities these technologies offer. How the war will impact Russia's future military innovation efforts is uncertain, but has at the very least placed new restraints on an already constrained defense ecosystem.

3.2 China

Reportedly impressed with the United States military's use of advanced technology during the 1990-1991 Gulf War and cognizant of the fact that they lacked the ability to prevent a foreign intervention in their own region, Chinese leaders embarked upon an ambitious and comprehensive program of military modernization during the 1990s. A second wave of reform and restructuring commenced in 2012 as Xi Jinping ascended to the presidency with a vision of restoring China's great power status and fielding a world-class military force (Maizland 2020). These lofty ambitions have been matched by steadily growing defense budgets that have experienced an annual increase for 20 consecutive years (OSD 2020, 142). At current exchange rates, China's $250 billion in military spending ranks second in the world, a figure that equates to over $470 billion using purchasing power parity (PPP). Although it remains difficult to achieve adequate transparency regarding China's military spending, these figures appear to constitute just two percent of the country's GDP (2011-2018), compared with four percent for Russia and over three percent for the United States (Oxenstierna et al. 2019, 104). This financial prioritization has supported substantial investments in its defense industry and innovation infrastructure, efforts that are laying the groundwork for the People's Liberation Army (PLA) to become a leading technologically advanced military power.

3.2.1 Current force structure

Even with recent reductions and restructuring since 2016, the *PLA Army* (PLAA) remains the world's largest standing ground force with approximately 975.000 troops. Equipping a force of this size is a formidable and expensive proposition, and according to the US Defense Department «significant additional equipment fielding is necessary to complete the transformation of the PLAA into a fully modern force» (OSD 2020, 45). Roughly 60% of China's nearly 6000 main battle tanks are considered modern. Combined arms units fielding armored vehicles – including armored personnel carriers and infantry fighting vehicles – are receiving new wheeled and tracked APCs and AIFVs, but estimates from 2019 suggest that a substantial portion remains outdated. One estimate considered at least half of PLAA armored vehicles, artillery and air-defense systems to be modern in 2020 (Boyd 2019).

The *PLA Air Force* (PLAAF) currently operates 2800 aircraft, including fighters, strategic and tactical bombers, and attack aircraft. According to the US Defense Department, the PLAAF is «rapidly catching up to Western air forces», a trend which is «gradually eroding longstanding and significant US military technical advantages» over China in the air domain (OSD 2020, 55). Approximately 50% of China's fighter aircraft are fourth generation fighters, including two dozen advanced fourth generation Su-35 fighters purchased from Russia. The stealthy fifth generation J-20 fighter has been fielded in limited numbers and the smaller FC-31/J-31 fighter is still in development, while the bomber fleet consists of a domestically produced version of the Soviet Tu-16 Badger. China operates and exports a substantial portfolio of UAVs, including the medium altitude long-endurance armed reconnaissance CH-4 and CH-5, as well as a number of other platforms (OSD 2020, 57).

The *PLA Navy* is the largest in the world measured in number of ship and includes major surface combatants, submarines, ocean-going amphibious ships, mine warfare ships, smaller vessels able to carry anti-ship cruise missiles, and several aircraft carriers. Since the 1990s, the PLAN has transformed from a coastal force to one that regularly operate offshore (DIA 2019, 69). China is in the midst of a substantial shipbuilding program – in 2016 alone, it commissioned 18 ships while the US Navy commissioned five – that includes new guided-missile cruisers, destroyers and corvettes. The PLAN operates two aircraft carriers: one partially built in the Soviet Union before its acquisition and completion by the PRC in the late 1990s, and the other based on a similar design yet domestically produced and launched in 2017. A third carrier, launched in June 2022 and expected to be operational by 2024, will utilize a modern catapult launch system for aircraft (Newdick 2022; OSD 2020, 50–52). The Chinese have also prioritized their submarine fleet. They currently operate six nuclear powered SSBNs, six nuclear-powered attack subs, and 46 diesel-powered attack submarines, the latter able to fire anti-ship cruise missiles. Through the 2020s, the PLAN is expected to operate between 65 and 70 submarines (OSD 2020, 49). Overall, a 2017 RAND Corp. analysis estimated that over 70 percent of the PLAN fleet could be considered modern (Maizland 2020).

China's *Rocket Forces* were elevated to an independent service in 2015 and operate a significant number of short-, medium-, and long-range ballistic missiles and ground launched cruise missiles, along with approximately 290 nuclear warheads compatible with its MRBMs and ICBMs. The Rocket Forces maintain China's strategic nuclear deterrent force, comprised of 75-100 ICBMs in silo-based and road mobile systems, with new ICBM models and silo fields under development (OSD 2020, 59–62). Chinese activities in space have grown steadily over the past several decades and include the BeiDou constellation of navigational satellites with global coverage, approximately 200 reconnaissance and remote sensing satellites, and a space-launch vehicle capability with heavy lift capacity. In September 2020, China successfully launched and recovered a reusable space plane after two days in orbit, making it only the third nation to have this capability (OSD 2020, 66). The Chinese space station Tiangong («Heavenly palace») is nearing completion in low earth orbit (Jones 2021).

The PLAs *Cyber forces* are organized under an independent branch known as the Strategic Support Force (SSF), a unit purportedly created specifically to rectify the disparity between US and Chinese cyber capabilities (OSD 2020, 64). A subunit of the SSF, the Network Systems Department, is responsible for cyberwarfare as well as technical reconnaissance, electromagnetic warfare and psychological warfare (OSD 2020, 65). Among its primary tasks are ISR, creating effects in the cyber domain, and incident response. Although definitive information on China's capabilities are scarce, a 2022 IISS analysis deemed it a «highly capable cyber power that has shown significant improvements in its military cyber capabilities in the last decade» (IISS 2022, 509).

In sum, China's current force structure is steadily modernizing its equipment and platforms, with particular emphasis on the air and maritime domains. Significant investments in new material over the past two decades show no signs of abating. Therefore, it seems likely that the PRC will be able to address the remaining gaps in its military modernization program – most notably land-based forces and advanced military aircraft – while it additionally funds expansive capability investments in long-range missiles and space assets. Given its current trajectory, China seems poised to have a fully modern and highly capable all-domain force within the next decade or so.

3.2.2 Defense innovation ecosystem

In the late 1990s, China's defense industrial base «possessed one of the most technologically backward defense industries in the world», with poor quality control, deficient research and development efforts in a number of key areas, an inability to integrate the various highly technical elements needed for advanced weaponry, and challenges in turning prototypes into successful production runs (Bitzinger et al. 2011). In the past two decades, however, the country's defense industry has undergone an impressive revitalization effort, matched by significant research and development spending (Zaharia 2018). China has largely employed an «absorptive» innovation approach based on acquiring foreign technologies in order to copy or reverse engineer them, an effort greatly enhanced after gaining World Trade Organization membership in 2001(Cheung, Lucyshyn, and Rigilano 2019, 18). In certain sectors such as naval or aerospace engineering, progress has been significant but falls short of independent and unique R & D efforts beyond incremental improvements to existing designs.

China's defense industrial sector is centrally managed with the Central Military Commission (CMC) overseeing research, development, and acquisitions for the military while the State Administration for Science, Technology, and Industry for National Defense (SASTIND) oversees state-owned defense industrial efforts in areas such as aerospace/missiles, maritime, aviation, ground systems and ordnance, electronics and nuclear (DIA 2019, 49). The country's defense sector is substantial. According to a recent analysis, it comprises «11 large state-owned defense enterprises with 1,400 subsidiary entities, over 300 research institutes and employs over 1.85 million people» (Cheung, Lucyshyn, and Rigilano 2019, 15). For several decades, the PLA has understood the inherent weaknesses of this domination of state-owned enterprises within China's defense industry as an inhibiting factor to greater efficiency and adaptability, but has struggled to overcome these structural impediments (Klungtveit 2021, 16). Previous attempts to create military-civilian synergies proved fruitless, in part due to the lack of overlap between civilian technologies and specific military needs such as afterburning turbofan engines or electronic countermeasures (Cheung 2014, 190).

A series of reforms in 2016 sought to reduce bureaucracy, streamline development and innovation processes, and establish a formal cooperative link between defense-oriented and civilian industries. In public statements, President Xi Jinping emphasized the importance of this civilian-military fusion, particularly in light of the anticipated future military application of certain civilian technologies. Despite these reforms, the participation of civilian industrial partners appears to be fairly limited, particularly regarding upper-tier components with direct military applications (Cheung and Hagt 2020). China has nevertheless reportedly invested hundreds of billions (US dollars) into commercial enterprises to develop dual use technologies and advance the PLAs modernization efforts (OSD 2020, 147). A comprehensive and highly structured system of academic exchanges – often disguising individual links to the military – provides China with an additional source of cutting edge scientific knowledge, as well as retaining highly skilled researchers (Joske 2018). The growing number of internationally competitive Chinese technology firms are an additional

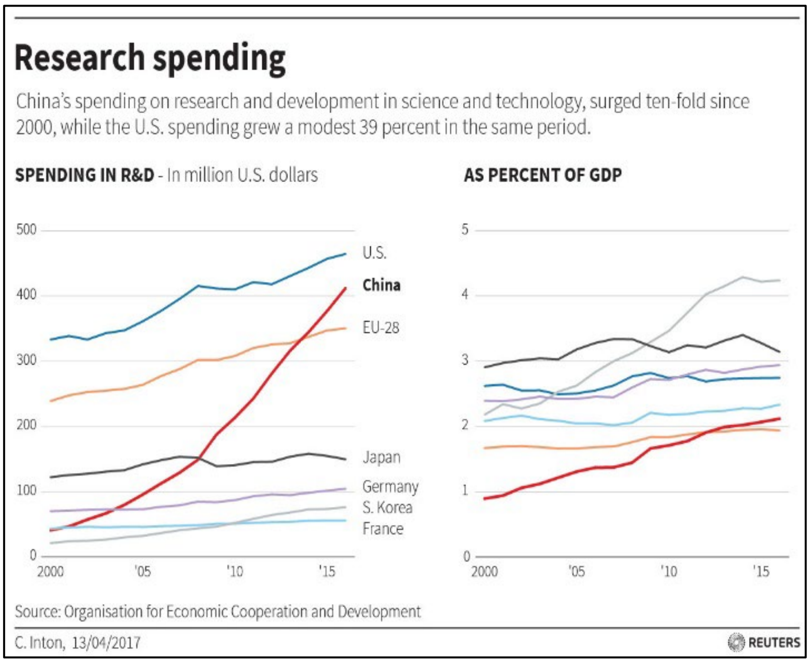

Figure 3.2 R & D spending by country through 2017 (Zaharia 2018)

factor in the country’s current and future innovation ecosystem, including companies such as Alibaba, Tencent, and Huawei (Dychtwald 2021).

The PRC has clearly made substantial progress over the past two decades regarding defense innovation, placing particular emphasis on self-reliance within a number of crucial industries. Domestic production sources now supply much of the PLAs equipment needs and China has become the world’s second largest arms producer behind the United States (Maizland 2020). Even so, it has yet to match the cutting-edge defense technologies of the United States or Western Europe, particularly with regard to propulsion and electronics (Cheung 2014, 203). According to one source, «Chinese arms are less expensive than those offered by other top international arms suppliers. They also are generally considered to be of lower quality and reliability» (DIA 2019, 107). As one US governmental analysis noted in 2020, «the PRC uses imports, foreign investments, commercial joint ventures, mergers and acquisitions, and industrial and technical espionage to help achieve its military modernization goals» (OSD 2020, 146). In areas such as hypersonics and digital simulations, China has legally gained US-developed information and technical knowledge through grants and contracts with university and commercial sector actors (Cadell and Nakashima 2022). In many respects, China remains a «fast follower» rather than a defense innovator in its own right. The often-used axioms regarding Chinese defense modernization – «China has come a long way» and «China has a long way to go» – appear to remain applicable (Cheung 2014, 203).

3.2.3 Emerging technology priorities

In March 2021, Chinese leaders revealed the country’s 14th five-year plan for investment and development, announcing their intention to make «science and technology self-reliance and self-improvement a strategic pillar for national development» and signaling a seven percent annual increase in research and development funding to pursue «major breakthroughs» in technology. According to media coverage of the announcement, China will prioritize seven so-called «frontier technologies» through 2025 and beyond: artificial intelligence, quantum information, integrated circuits or semiconductors, brain computer interfaces, genomics and biotechnology, clinical and regenerative medicine, and «deep» exploration into space, earth, sea and polar regions (Kharpal 2021).[13] Nearly all of these emerging technologies have direct military applications.

After years of investment in state-led science and technology programs, China is well-positioned to conduct research on emerging technologies such as AI, quantum technology, advanced materials and manufacturing, and biotechnology. The country is already a leader in high-speed railways, electric vehicles, big data analysis, and cloud computing. In particular, China’s National Artificial Intelligence Plan seeks to make the country the «world’s major AI innovation center» by 2030 and in 2020 the PRC’s Ministry of Science and Technology identified over 20 AI research tasks (including brain-inspired software, human-machine teaming, swarming, and decisionmaking) for which approximately $85 million was being allocated (OSD 2020, 146). The

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[13] In a speech to the 20th national Communist Party Congress in October 2022, President Xi reiterated many of these same priorities, mentioning seven «emerging strategic industries»: next-generation information technology; artificial intelligence; biotechnology; new energy; new materials; high-end equipment; and green industry (Yatsuzuka 2022).

Pentagon's chief software officer resigned in 2021 out of frustration over the US military's ineffective digital transformation, claiming that China had already won the global AI competition and that the US had «no competing fighting chance against China in 15-20 years» (Reuters 2021).

China has already invested heavily in several other «frontier» technologies, including quantum science and biotechnology. Quantum technologies have a multitude of potential military applications including computing, sensing, communications, cryptography, and navigation. In 2016, China demonstrated its commitment to becoming a leader in quantum technology with the launch of Micius, a satellite purpose-built for experimenting with quantum-encrypted communication that successfully conducted an encrypted virtual teleconference between Beijing and Vienna the following year (Kwon 2020). China has already constructed a 2000 km ground-based quantum-secure communications line between Beijing and Shanghai with the intention of expanding it across the country (OSD 2020, 146). In biotechnology, brain science, and genetics, China has charted a course to leverage the dual-use nature of these technologies to pursue cutting-edge research on medical procedures as well as techniques ranging from the creation of biological weapons, enhancing interfaces for human-machine teaming or enabling genetically enhanced personnel (Chen, Andriola, and Giordano 2018).

China is following an ambitious and well-funded strategy to develop impactful emerging technologies. According to some analysts, China is pursuing «truly disruptive, even 'radical' innovation'…seeking to leapfrog the United States to seize the 'commanding heights' in those emerging technologies critical to future power, including biotechnology, artificial intelligence, and quantum technologies. These megaprojects are undertaken in the tradition of Chinese techno-nationalism» and may present the United States and its allies with «technological surprises» (Kania and Costello 2018).

3.2.4 Doctrinal and organizational adaptations

The 1990-1991 Gulf War represented a significant inflection point for Chinese strategists, drawing lessons regarding the utility of integrating information technology to coordinate and implement modern maneuver warfare in ways now referred to as network-centric warfare. Of particular interest to the PLA was the operational use of space-based command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) (Costello and McReynolds 2018, 7). The resulting warfighting doctrine used by the PLA is «informationized warfare», which describes «the process of acquiring, transmitting, processing, and using information to conduct joint military operations across the domains of land, sea, air, space, cyberspace, and the electromagnetic spectrum during a conflict» (DIA 2019, 24). The Chinese therefore used the following decade to create a robust space-based C4ISR network using Beidou navigational satellites, space-based surveillance platforms and dual-use communication relays to provide a regional ISR and precision strike capability (Costello and McReynolds 2018, 7).

A second lesson gleaned by Chinese military strategists was the vulnerability of information networks to asymmetric disruption, where one might «overcome the superior with the inferior» by targeting «critical nodes» in space, cyberspace, and within the electromagnetic spectrum

(Costello and McReynolds 2018). Watching the steady build-up of US and allied forces in the Middle East during the 1990-1991 conflict led China to conclude that an effective defense entailed preventing an adversary such as the United States from massing combat power near China's borders. This combination of asymmetric disruption and preventing regional power projection has been termed, as noted in the discussion of Russian thinking above, anti-access/area denial capabilities, a concept seemingly more appropriate for East Asian theatre than Europe (Burke et al. 2020; Dept of the Army 2021).

The operational concept of «informationized» warfare therefore implies long-range standoff weapons, cyber warfare, electromagnetic warfare, and counter-space assets, with a particular focus on the maritime domain around China. Electromagnetic warfare and cyber capabilities are particularly prominent elements of Chinese military doctrine, focused on «suppressing, degrading, disrupting, or deceiving enemy electronic equipment» and an early use of these capabilities during a conflict «as a signaling mechanism to warn and deter adversary offensive action» (OSD 2020, 87). Deception plays an especially important role in Chinese thinking with doctrinal roots dating back to Sun Tzu, and is integrated at all levels of warfare (Dept of the Army 2021, 1–13).

Even with these substantial adaptations, Chinese military strategists are preparing for yet another doctrinal shift. As a 2021 US Army report notes:

> The PLA anticipates Informationized Warfare evolving into Intelligentized Warfare in the relatively near future. Intelligentized Warfare incorporates numerous emerging technologies including decentralized computing, data analytics, quantum computing, artificial intelligence, and unmanned or robotic systems—into the PLA's conceptual framework. Intelligentized Warfare seeks to increase the pace of future combat by effectively fusing information and streamlining decision-making, even in ambiguous or highly dynamic operating environments (Dept of the Army 2021).

This new form of warfare will increase the speed and tempo of operations, necessitating the integration of artificial intelligence for information processing and decisionmaking. According to the US Defense Department, the PLA is «exploring next-generation operational concepts for intelligentized warfare, such as attrition warfare by intelligent swarms, cross-domain mobile warfare, AI-based space confrontation, and cognitive control operations» (OSD 2020, 89).[14]

Unlike Russia or the United States, however, the PLA has not tested any of their current doctrines or concepts in operational situations. Whereas the Russian and American military have garnered operational experience and lessons from their various deployments, the Chinese military has not seen combat in the 21st century. Instead, Chinese forces joined their Russian neighbors in a 2018 large-scale exercise, and have participated in United Nations operations to gain additional deployment experience (Gowan 2020; Z. Yang 2018). The net effect of a modern, well-financed military without operational experience may be difficult to gauge. As one RAND analyst concluded, « [c]ombat experience thus matters for China at the operational and strategic levels,

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[14] See also (Takagi 2022).

but its significance can be overstated. At the operational level, other factors such as leadership, training, preparation, and motivation are more responsible for determining military effectiveness on the battlefield» (Heath 2018).

In sum, China's military is becoming increasingly modern although significant weaknesses persist, its state-centric defense industrial ecosystem is well-funded and motivated to achieve greater integration with civilian R & D entities on a host of cutting-edge «frontier» technologies, and Chinese military strategists have demonstrated doctrinal flexibility, learning and adapting to changing military-technological realities.

3.3 United States

Having emerged from the Cold War as the sole remaining «superpower» capable of global force projection, the United States retained its expeditionary force posture and a substantial network of military facilities spanning the globe as it sought to establish its role as an international security provider. Even so, the US sought a so-called peace dividend and reduced its defense spending from roughly eight percent of GDP in 1988 to just under four percent by 2000. Spending increased again after 2001 in connection with the global war on terrorism and associated conflicts in Afghanistan and Iraq, although defense budgets remained between three and five percent of GDP (Walker 2014). Defense spending totaled just over 800 billion USD in 2021, constituting 38 percent of all global military spending (Da Silva et al. 2022). Given the country's global ambitions and high operational tempo, however, the US military experiences continuous budgetary pressure as it balances operational costs with materiel investments and ongoing innovation efforts.

3.3.1 Current force structure

The unique structure of the armed forces in the United States somewhat complicates a domain-based force structure assessment: the US Army operates rotary and some fixed-wing aircraft, the Navy wields significant fixed-wing air power from its carriers along with the Marine Corps land forces specializing in amphibious assault. US *ground forces* are comprised primarily of 638.000 active duty personnel (US Army and US Marine Corps) and operate an estimated 6000 MBTs, over 40.000 armored vehicles, and 1500 self-propelled artillery. The average age of all tanks and other armored vehicles and artillery are between eight and thirteen years, a number representing significant refurbishment and modernization levels (Keating and Adedeji 2021).

US *naval forces* are, by any measure, the world's most capable blue water fighting force, consisting of nearly 343,000 personnel and operating roughly 300 vessels. This includes 11 aircraft carriers, and numerous large surface combatants, amphibious warships, smaller surface vessels, and nuclear-powered attack submarines. The fleet is ageing, however, with ten classes of ships in the US fleet having reached the halfway point in their expected service life. Notably, the US has a significantly higher missile density (average number of missile launchers per vessel) than either Russia or China, although China operates a greater number of platforms. In addition to the naval vessels, the US Navy operates EA-18 Growler electronic attack aircraft and F/A-18

Super Hornet fighter/attack aircraft will be replaced with several variants of the F-35 Joint Strike Fighter (Heritage 2021).

The *US Air Force* currently operates the most advanced and capable aircraft fleet in the world, having procured two types of 5th generation fighter aircraft, the F-22 and the F-35A Joint Strike Fighter. These two systems will eventually replace a number of ageing airframes, including the A-10, F-15C, and F-16C. The US also operates a substantial air refueling fleet, with newer KC-46 aircraft gradually replacing the outdated KC-135s. Another significant air capability is the fleet of medium (newly upgraded C-130Js) and heavy transport aircraft (C-5M Galaxy aircraft and C-17 Globemasters, with an average fleet age of 34 and 19 years, respectively), which currently do not have a planned replacement program. The majority of airborne ISR tasks have been assumed by unmanned aircraft such as the larger RQ-4 Global Hawk and the medium altitude long endurance MQ-9 Reaper. Among the manned platforms are RC-135s for electronic surveillance and the venerable U-2 Dragon Lady high altitude ISR platform which entered into service in 1956 and has been upgraded numerous times during its long service life (Heritage 2021).

The strategic forces of the United States follow the traditional triad structure of long-range strategic bombers, ballistic submarines, and land-based ICBMs. The bomber fleet consists of B-52s that first entered service in the 1950s but which have been substantially modernized and upgraded over the past decade, and able to carry both conventional and nuclear payloads. Two other strategic bomber platforms, the B1B Lancer and the B-2 Spirit, are slated to be phased out in favor of the B-21 Raider by 2032. The Ohio class SSBN ballistic submarines first entered into service in the early 1980s and had an original retirement date in the 2010s but will remain in active service until the first of the new Columbia-class deploys in 2031. The silo-based Minuteman III have been in active service for fifty years and are slated to be phased out, replaced by the new Ground Based Strategic Deterrent program starting in 2029. The Missile Defense Agency continues to develop short-, medium- and long-range ballistic missile defenses, including research into intercepting hypersonics. The newly created Space Force has responsibility for a warfighting domain that is growing, both in strategic importance and in terms of numbers of communication satellites and space-based sensors (Olson et al. 2022).

The US *Cyber Command*, which became a combatant command in 2018, leads cyber forces within all service branches with the exception of the newly-created Space Force. The primary tasks associated with cyber forces are ISR, incident response, and creating effects in the cyber domain. Assessed by IISS as the world's most capable cyber power, the US seeks to maintain its dominant position and «defend forward» to deter threats (IISS 2022, 510). The US has been seen as a pioneer of sorts regarding offensive cyber operations after its likely role (along with Israel) in the Stuxnet cyberattack from 2009 (Nakashima and Warrick 2012). According to a database administered by the US Council on Foreign Relations (CFR), the US has likely conducted operations against additional targets in states such as Iran, North Korea, and Russia (CFR 2022).

In sum, the United States fields the largest and most modern military force in the world, with significant modernization plans within each domain. A significant number of platforms are reaching the end of their expected service life, and the political debate continues regarding the future composition of the US force structure. Despite relative gains by China, particularly regarding quantitative gains in total surface vessels, the overall military capability of US systems remains dominant.

3.3.2 Defense innovation ecosystem[15]

In contrast to the more state-controlled defense innovation ecosystems of Russia and China, the United States has a less hierarchical and structured defense industrial base that makes it more flexible and adaptable yet more challenging to organize and steer effectively. The coordination challenge to efficiently distribute acquisition contracts and R & D funding across such a wide range of actors and interests leads inevitably to structural inefficiencies and duplications that might be avoided with a hierarchical state-controlled defense industry. Each year, tens of thousands of commercial enterprises – over 44,000 small businesses in 2020 alone – provide goods and services to the various entities within the US Defense Department totaling USD429 billion worth of contractual obligations (DOD 2021; NDIA 2022, 8).

This defense industry diversity offers a robustness and source of vitality with multiple companies able to provide similar products and systems, although industry consolidation has reduced this redundancy (DOD 2022). Since 1990, the number of US-based suppliers for tactical missiles has shrunk from 13 down to three prime contractors, fixed wing aircraft from eight to three suppliers, satellite manufacturers from eight to four, and surface ships from eight to only two prime contractors as of 2020 (DOD 2022). Additionally, commercial and military applications of various technologies combined in a single corporation offer explicit and implicit combining of civilian technology for military applications. On the other hand, the significant role of purely commercial actors in the defense sector can leave actors susceptible to market forces without measures to secure the longevity of the defense industrial base, which has often been the case for the United States (Berenson, Higgins, and Tinsley 2021).

Due to the hybrid nature of the US defense sector, research and innovation efforts are similarly disjointed and include a wide range of actors and investment motivations. Unlike purely commercial innovation, defense sector R & D entails a different set of investment dynamics, profit schemes, and industrial competition. Commercial actors in the defense sector are often hesitant to invest heavily in R & D without government funding given the regulatory structures governing profits, foreign government weapons sales, and the limited market available to reap the rewards of successful innovation (Dombrowski and Gholz 2006, 20–22). The largest defense industry actors sustain active independent research and development programs, but these are not necessarily aimed at basic technology research for potentially disruptive effects. Such high-risk innovation is often carried out at the substantial network of defense-oriented government funded research institutions.

In 2016, the US Congress re-established an entity within the Pentagon to oversee technology and innovation within the Department of Defense (Gallo 2021). The Under Secretary of Defense for Research and Engineering (USD R & E) includes federally funded research labs, Federally Funded Research and Development centers (FFRDC), defense-oriented academic research

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[15] A good Norwegian-language source on this topic is (Thorsberg et al. 2021).

through University Affiliated Research centers (UARC), manufacturing institutes, test and evaluation entities, and organizations tasked with coordinating DoD's innovation investments with the modernization priorities laid out in the National Defense Strategy. Other notable entities also fall within R & E's purview, including the well-known Defense Advanced Research Projects Agency (DARPA), the Missile Defense Agency, the Strategic Intelligence Analysis Cell, and the Space Development Agency (Griffin 2020).

The United States is a leading technology innovator and home to a significant number of well-known technology firms including Apple, Microsoft, Amazon, Facebook, Intel, Oracle, Qualcomm, and Nvidia. Compared with other leading technology countries, the US consistently ranks near the top when measuring indictors such as science and technology innovation, products developed, patents issued, and academic papers published (Dutta et al. 2021; UNCTAD 2021). This technology expertise need not necessarily benefit the defense innovation ecosystem, but adequate cross-sector pollination between the universities, FFRDCs, national laboratories, and the Defense Department's prime contractors ensures the development and production of highly advanced military systems (Gholz and Sapolsky 2021). For commercial technology that can quickly be adapted and adopted for military applications, the Defense Department created the Defense Innovation Unit (DIU) in 2015 to facilitate civilian-military partnerships. Dozens of other innovation facilitators operate across the defense ecosystem, many of them acting as venture capitalists (VC) offering seed money for promising ideas and technologies (Nurkin 2020). The primary inspiration for DIU appears to have been the CIA's In-Q-Tel, an entity established in 1999 functioning as a VC and working with technology start-ups to investing in promising ideas for the intelligence community (Gentile et al. 2021, 46).

3.3.3 Emerging technology priorities

The creation of DIU was part of a renewed focus on emerging technologies advocated primarily by Pentagon official and academic Robert Work through a framework known as the «Third Offset strategy» for leveraging emerging technology to counter the military power of potential adversaries. Although the concept resembled a set of ideas more than a strategic approach (and the previous two «offsets» were given their loosely fitting labels retroactively), it influenced the 2018 National Defense Strategy and remains a relevant framework for understanding the American approach to developing new military technology.

As Work and others described it, the First Offset sought to counter the overwhelming advantage of Soviet conventional forces in Europe with tactical and strategic nuclear weapons during the 1950s, while the Second Offset relied on satellite navigation, precision-guided munitions, stealth technology and improved C2 to defeat Soviet tank divisions during the 1980s. In the years following the successful application of these technologies against Iraq in 1990-1991, regional adversaries such as China and Russia developed their own PGM, C2 networks, air defenses, and long-range missile systems to deny access and control to any potential use of US military forces. For Work, the means to counter these A2/AD capabilities, and thus retain the ability to credibly deter these actors and reassure allies in Europe and the Pacific of Washington's security commitments, required investments in artificial intelligence and autonomous systems to be successful. The unveiling of China's new J-20 stealth fighter, which bore a remarkable resemblance to the US F-22 aircraft, prompted additional concerns about Chinese corporate espionage and protecting US technological advantages. Technological innovation within companies such as Google and Apple had «begun to outpace the work of their public and semipublic counterparts» and the outdate regulatory system, so that «in many key fields, the private sector, not the Pentagon, was driving innovation», a situation that «complicated the acquisition process and also made it significantly more difficult to maintain any kind of technological edge, given China's access to American high-tech industries and its role in the global supply chain» (Gentile et al. 2021, 25).

The Third Offset concept therefore combined a renewed focus on a specific set of emerging technologies with an emphasis on harnessing the potential – and safeguarding the intellectual property – of the rapidly growing US technology industry. While the Third Offset strategy was less a strategy than a concept for military innovation that dissolved after Work's exit from the Pentagon in July 2017, the combination of ideas and motivations for defense innovation remain one of the most relevant lenses through which to view US efforts to develop EDTs for military applications.

The breadth and depth of American commercial activities relating to emerging technologies – it is with good reason that «Silicon Valley» became an iconic phrase – means that some activity relating to most emerging technologies can be found in the country, although not all are equally prioritized by the defense industry. In re-establishing the position of USD (R&E) in 2016, the Senate Armed Service Committee stated that the entity «would be tasked with driving the key technologies that must encompass what defense leaders are now calling a 'Third Offset' strategy: cyber and space capabilities, unmanned systems, directed energy, undersea warfare, hypersonics, and robotics, among others» (Gallo 2021). Under Secretary Heidi Shyu released a memorandum in February 2022 outlining an ambitious agenda to «nurture early research and discover new scientific breakthroughs to prevent technological surprise» (Shyu 2022). The memo detailed 14 critical technology areas deemed vital to US national security, divided into three categories:

- *Seed areas of emerging opportunity*: biotechnology, quantum science, future generation wireless technology, advanced materials

- *Effective adoption of existing commercial sector activity*: AI and autonomy, integrated network system-of-systems, microelectronics, space technology, renewable energy generation and storage, advanced computing and software, human-machine interfaces

- *Defense-specific areas*: directed energy, hypersonics, integrated sensing and cyber capabilities «to develop wideband sensors to operate at the intersection of cyber space, electromagnetic warfare, radar, and communications»

These priorities echoed statements by the previous USD (R&E) Michael Griffin in Congressional testimony, as well as a National Strategy for Critical and Emerging Technologies issued by the White House in October 2020 (Griffin 2020; White House 2020). There is ample evidence of innovation efforts within the US military in many of the areas listed above. An AI initiative will harvest data and establish data management platforms to encourage trust (Cronk 2021), an armed autonomous aircraft prototype (a so-called «collaborative combat aircraft» or «loyal wingman» concept) is undergoing testing (Trimble and Hudson 2020), research into quantum sensing has led to the creation of a prototype able to detect a broad swath of the electromagnetic spectrum (Tucker 2021), and the US Navy is preparing for a future fleet augmented by unmanned surface vessels (Katz 2021). Funding for emerging technologies reflects these priorities within the Defense Department's budget request of $112 billion for research and development, including over $870 million for over 600 AI active projects and $570 million for directed energy research (Sayler 2021; Towell 2021). Efforts to combine these new technologies into meaningful military capabilities include the US Army's «Project Convergence» effort comprising a series of high-profile tests and exercises aimed at integrating technology and tactics in the still evolving multi-domain warfare concept (Osborn 2021). Some critics suggest, however, that the overall effort lacks coordination and direction (Work, Winnefeld, and O'Sullivan 2021).

3.3.4 Doctrinal and organizational adaptations

Achieving effective integration between the service branches is a persistent feature of modern US doctrinal thinking and operational planning. The most recent wave of operational «jointness» is rooted in the 1986 AirLand Battle doctrine that outlined a coherent approach to combining air and land operations to defeat the Soviet military in Europe. While the concept remained untested against its intended adversary, the US successfully applied many of the principles and new capabilities developed for AirLand Battle against Iraq in 1990-1991 (Johnson 2018). In the early 2000s, with the emergence of China as a strategic competitor and the re-emergence of Russia as a regional threat, concerns over both actors' development of A2/AD capabilities and operational concepts focused on attacking US battlefield networks led to a renewed effort to find integrated joint warfighting solutions.

With an initial focus on countering Chinese military might in the region, an AirSea Battle concept emerged as a potential successor to AirLand Battle, with its emphasis on force integration primarily directed at air and naval forces due to the maritime aspects of the Asia Pacific theatre. As one Defense Department report noted, the concept's answer to A2/AD challenges in the global commons was «to develop networked, integrated forces capable of attack-in-depth to disrupt, destroy and defeat adversary forces», a goal requiring «the application of cross-domain operations across all the interdependent warfighting domains (air, maritime, land, space, and cyberspace)…to provide maximum operational advantage» (DOD 2013, 4). International criticism that the concept represented an unnecessary provocation to China and internal dissatisfaction over the lack of a clear role for the US Army led the Pentagon to discard the Air Sea Battle name in 2015, although the concepts remained relevant for American military thought (LaGrone 2015).

To a greater degree than Russia and in contrast to the Chinese PLA, the US military has been operationally active almost continuously since the end of the Cold War. In the wake of the September 2001 attacks, US forces have conducted a large-scale conventional invasion as well as sustained counterterrorism and counterinsurgency operations for over two decades. While not entirely applicable to the anticipated challenges of great power conflict, these military operations provided countless lessons and opportunities for tactical innovation ranging from countering improvised explosive devices to the use of unmanned systems via satellite links for persistent overhead surveillance and extremely short kill chains. Operational experience formed an important foundation for the further evolution of military doctrine in the United States.

The next operational concept, this time from the US Army, expanded upon the cross-domain synergies introduced in these earlier proposals. Still focused on A2/AD challenges and with an additional emphasis on «narrow physical dimensions that favor enemy fait accompli efforts», the challenge became one of «how to create depth and, by doing so, maneuver room to enable a US advantage» (Wesley and Simpson 2020, 6). The answer, according to the new Multi-domain Operations (MDO) concept, was to coordinate military efforts across all domains – notably with the inclusion of cyber and space – and within tactical, operational, theater and global «echelons» simultaneously. The overall idea would be for the US Army to «penetrate and dis-integrate enemy anti-access and area denial systems and exploit the resultant freedom of maneuver to achieve strategic objectives (win) and force a return to competition on favorable terms» (US Army 2018, 17). Accomplishing multi-domain maneuver would require advanced protection systems, reduced signatures, robust communications, and an ability to employ cross-domain fires. An important feature was that of convergence, the «rapid and continuous integration of capabilities in all domains, the EMS, and the information environment that optimizes effects to overmatch the enemy through cross-domain synergy and multiple forms of attack» (US Army 2018, 20).

Within a few years, MDO had evolved into its current iteration, Joint All Domain Operations (JADO), which retains much of the thinking reflected in MDO but further integrates cyber and space assets along with an emphasis on global force management. As Vice-chairman of the Joint Chiefs of Staff General John Hyten remarked in February 2020, JADO is «just an expansion of the combined arms problem to air, land and sea, plus space and cyber» (C. Clark 2020). In order to operate and coordinate efforts on a global scale, the US military has been developing Joint All-Domain Command and Control (JADC2) to supply commanders with information to «enable simultaneous and sequential operations using surprise, and the rapid and continuous integration of capabilities across all domains», as described by a Congressional report (Hoehn 2021). Current C2 structures are inadequate for the speed and complexity this will entail, given the expected role of autonomous systems, anticipated resiliency requirements within an electromagnetic warfare environment, latency issues from existing space-based assets, and the limits of human cognition. Providing an adequate solution to such challenges will entail a complex network of advanced technologies, including the integrated use of artificial intelligence and autonomous systems in decision loops as detailed in a series of DARPA-sponsored projects known collectively as Mosaic warfare (B. Clark, Patt, and Schramm 2020).

In sum, the United States fields the world's most advanced military force, with modern combat systems on land, air, sea, and a space-based network of ISR and communication satellites. Although some weaknesses and modernization needs exist, the US remains the most modern and capable military even as China makes relative gains. A key advantage – as well as a challenge in terms of re-investment and doctrinal development – has been the country's two-decade long focus on counterinsurgency and counterterrorism operations in the Middle East and Central Asia, from which US forces gained valuable experience. The US defense industrial base, given its complete integration with the civilian commercial market, has unfettered access to technological advances and expertise through a number of governmental programs and sponsorships. US leaders have focused on a broad range of emerging technologies and are developing new doctrinal concepts to integrate these technologies into future military operations.

4 Assessing disruptive technologies and future force structures

State actors devote substantial resources to developing new technologies, systems, and warfighting concepts with the expectation of gaining operational advantages, but the precise effects of these developments on military operations remain unclear. One way to understand how emerging technologies might influence future operations is to assess the impact of those technologies on some of the most basic warfighting functions. According to US and NATO doctrine, seven fundamental warfighting functions are essential for joint operations: command and control (C2), intelligence, fires, movement and maneuver, protection, sustainment, and information (NATO Standardization Office 2019; US Joint Chiefs of Staff 2017). An analysis assessing how some or all of these joint functions might be influenced by technological changes can potentially give us an idea of the future force structures states are likely to field. As military technologies mature and become operational systems, decisionmakers and military leaders are likely to invest in systems that allow militaries to better perform these basic functions.

Few warfighting functions remain unaffected by technological progress and a thorough analysis of any one function constitutes a report unto itself. Each represents an important facet of military operations that could be decisive in a conflict. For the sake of simplicity, this report examines just four modified functions – *move*, *sense*, *communicate*, and *shoot* – representing core tasks for military units that are likely to be influenced by emerging technology.[16] Clearly, other functions are highly relevant as well, including gaining an understanding of the conflict environment or sustaining military forces engaged in operations. These and other areas may be included in future analyses. Even an analysis of the rudimentary move-sense-communicate-shoot typology quickly becomes a complicated affair given the number of interrelated variables at work.

4.1 Current warfighting function parameters[17]

Understanding how emerging technologies will affect these four simplified warfighting functions requires establishing a rough «baseline» for each function. A useful concept from the business world, *performance trajectories*, has been defined as «the rate at which the performance of a product has improved, and is expected to improve, over time» (Bower and Christensen 1995). Certain «sustaining» technologies maintain the current rate of improvement, whereas «disruptive» technologies have unique and market-altering characteristics, a distinction similar to that made in section 2.2 describing military innovation. Adapting the basic concept of performance trajectories to warfighting functions provides a rough parallel to defense planning calculations. A set of parameters that appears fundamental for each of the four warfighting functions (move, sense, communicate and shoot) is a collection of basic properties such as *speed, range, volume, stealth, precision*, and *security/robustness*. There is an implicit relationship

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[16] Chairman of the Joint Chiefs Gen. Mark Milley composed a somewhat similar list of priorities when conceptualizing what is now Army Futures Command (Judson 2022).

[17] A significant source for both inspiration and data for this section was Michael O'Hanlon's Brookings paper *Forecasting change in military technology, 2020-2040* (O'Hanlon 2018).

between performance and acquisition policies. As we have seen in chapter three, states must balance the acquisition of new systems with modernization and maintenance costs associated with existing force structures. Elements are replaced with new systems or capabilities promising incrementally better performance at an acceptable cost, but potentially disruptive systems representing such a dramatic improvement that actors feel compelled to acquire it for fear of falling off the «treadmill» may also be acquired at much greater cost. The following pages offer a simplified analysis of the current relevant performance criteria in an attempt to establish a tentative baseline as a means of determining whether emerging technologies might represent incremental or disruptive change in military operations.

4.1.1 Move

Battlefield mobility involves the ability to move and maneuver forces in an advantageous manner at the tactical, operational or even strategic level. Speed, distance and precise navigation are fundamental aspects of mobility at all three levels, as is an ability to move sufficient numbers without detection in tactical situations. Many of these parameters have remained surprisingly constant for decades. Individual soldiers traveling by foot loaded with gear have a speed and range that varies wildly according to physical fitness, terrain, and weather conditions. For ground-based vehicles, designs usually entail a series of compromises between characteristics such as protection, armaments, fuel efficiency and speed. Although engine performance and crew protection have increased substantially, main battle tanks and light vehicles from the post-World War II era exhibit fairly similar speed/range performance characteristics compared with today's systems. Heavier armored vehicles are likely be transported first via railway or by trucks, rather than moving under their own power – making road and rail infrastructure a banal yet highly relevant aspect of mobility at the operational and strategic levels (Vershinin 2021).

A similar story is evident in the air. Despite incremental improvements to range and payload capacity, the basic mobility parameters for transport, bombers, and fighter/attack aircraft have remained relatively stable for decades. The helicopter introduced a unique capability in the 1940s, however, as did unmanned aircraft remotely piloted via satellite link during the 1990s. At sea, the physical laws of hydrodynamics limit larger displacement surface vessel speeds, whereas smaller vessels designed to «plane» on the sea surface are capable of greater speeds but with significantly reduced ranges and carrying capacities. The advent of nuclear-powered vessels in the 1950s greatly increased the range of surface vessels such as aircraft carriers, along with the speed and range of submarines. The characteristic most significantly altered at sea and in the air is that of signature reduction. Comparisons between the radar cross sections of fighter aircraft, newer surface vessels such as the US Zumwalt class, and sonar signatures of modern submarines (particularly with air-independent propulsion) show significant reductions.

Mobility is reliant on access to accurate position, navigation, and timing information. The advent of global navigation satellite systems (GNSS) has allowed military, commercial and civilian users to instantly and reliably fix their position on the globe. The orbital paths of satellites remain bound by celestial physics and have various properties based on shape, inclination relative to the equator, and altitude. Objects in low earth orbit (LEO) operate at altitudes of 160-2000 km, while geostationary earth orbit (GEO) constitutes the outer extreme at nearly 36.000 km. As of 2017, ninety percent of all satellites were either in LEO (55%) or GEO (35%). The medium earth orbit (MEO) altitudes between LEO and GEO are an advantageous compromise of surface coverage and communications delay, exemplified by the 24-satellite constellation of the Global Positional System (Roberts 2022). Earth orbits are increasingly congested as more nations and commercial entities place satellites in space, with space debris also posing a growing risk to space activities. Some spacecraft, as recently demonstrated by a Chinese SJ-21 satellite, are able to maneuver close enough to attach to other satellites and even pull them out of orbit (Tingley 2022).

Mobility in the cyber domain is less intuitive than in the physical domain, but the parameters remain quite relevant. Although often overlooked, the physical infrastructure of the civilian-based internet and other governmental fiber optic connections are crucial information highways that represent a significant geopolitical factor susceptible to disruption due to natural disasters or targeted attacks. Whereas in many situations, «how fast» represents something close to the speed of light for data transfers along these digital highways, satellite digital communication experiences small yet significant microsecond delays, and slightly larger delays are present in wireless connectivity. The expansion of the global internet and the subsequent growth of wireless-enabled devices (the «Internet of things») has expanded digital mobility, although some states have erected barriers to entry. Despite monitoring tools, the ability to move about digitally without detection remains widespread, although leveraging that access undetected is much more difficult.

4.1.2 Sense

Sensing has in essence three fundamental parameters: the amount of data collected, the range at which objects can be detected, and the precision with which measurements can be made. The human eye is able to discern shapes and movement at great distances and poor light. Even so, a soldier standing on flat unobscured terrain is limited to a sight line of roughly five to ten kilometers due to the curvature of the earth. Optical tools such as spotting scopes or binoculars can enhance visual sensing at elevation by as much as 100 times, although increased magnification reduces the field of vision. Using other wavelengths than visible light allows an even better view of the battlefield. Infrared sensors of various types can detect thermal emissions of objects such as humans or vehicles. Night vision devices (NVD) amplify ambient light, while the most recent version Enhanced Night Vision Goggle-Binocular (ENVG-B) combines light amplification, thermal imaging and augmented reality to provide outlines of partial images and navigational and informational overlays (Brown 2021; Kushiyama 2015).

Platform-based sensors include radar, ultraviolet (UV), LIDAR (light distance and ranging), or electro-optical (EO/IR) imaging that incorporates daylight video cameras and thermal imaging. For ground forces, the addition of smaller tactical UAV sensors with some type of EO/IR sensor broadcasting an image back to its operator provides an elevated view of the battlefield as well. Vehicle-mounted radars can detect and track mortar, artillery and rocket fire at ranges approaching 30 kilometers, while more powerful transportable missile and air defense sensor can identify targets thousands of kilometers away. Despite technological advances, sensors using line-of-sight electromagnetic radiation will remain hindered by basic physical properties such as the earth's curvature or, depending on the type of sensor, certain features such as foliage, water, or soil. New types of camouflage obscure electromagnetic waves and partially counter the ability of certain sensors to register objects clearly, giving their users precious seconds on the battlefield. The contest between «hiders» and «seekers» on the ground is far from over, although remaining hidden has become increasingly difficult (Dalløkken 2019; Economist 2022b).

On the ocean's surface, larger vessels carry powerful radars using one or more frequency bands to detect airborne threats at nearly 1000 km, but their own positions are difficult to obscure. Under the sea, submarines (as well as anti-submarine warfare surface ships) rely on active and passive sonar for sensing, with ranges extremely dependent on water temperature and conditions (from only a few kilometers in poor conditions to over a hundred kilometers in optimal conditions) (Miasnikov 1995). Airborne sensors utilize much of the same types of sensors as those on the ground, but also include synthetic aperture radars (SAR) that uses the motion of the aircraft to create either two- or three-dimensional scans of their environment. At higher altitudes, satellites use SAR, laser and radar altimeters, and powerful EO/IR sensors to monitor the earth's surface.

The collection of relevant information beyond the physical location of an adversary's assets has long been of interest and includes collecting signals intelligence (SIGINT) from communications intercepts or other data transmissions. Information gathering in both the electromagnetic and cyber domains use a different set of tools than in the physical world, but with many parallels and common features. The spread of the global internet and «internet of things» generates an overwhelming volume of data and its interconnectedness potentially allows access to unprecedented amounts of open source information. Powerful automated search engines leveraging machine learning algorithms can analyze and label extraordinarily large volumes of freely accessible online data. Other tools perform similar analyses for those parts of the internet that are less readily available to the general public.

4.1.3 Communicate

The third function, communication, is essential for command and control (C2) functions and can be evaluated in accordance with three main parameters: the range and speed at which communication can be accomplished, how much data can be transferred, and the security of the communication's content and ability to reach its intended recipient. Human voice communication remains a fundamental component of military operations. Coordination between ground units as well as ground-to-air communication often relies on line of sight radio frequency (RF) communications via VHF/UHF radio links. While ranges are highly dependent on terrain, structures such as buildings, or even atmospheric conditions that affect propagation, a maximum VHF range of 100 kilometers and UHF range of approximately 60 kilometers can be expected. The same portable radio units can also be equipped with frequencies enabling satellite voice and data (text messaging, images, etc) communication, as well as via standard tactical data links such as Link 16 (White 2020). Although military and civilian actors have been able to utilize satellite communication for at least three decades, this qualitative leap substantially improved the speed and range of voice and data transmissions. Protecting RF communication from detection, interference, or interdiction has been a continuous struggle since its inception, although modern radios employ frequency-hopping transmissions to increase their security.

The convenience and speed associated with digital communication has brought its own set of vulnerabilities such as unauthorized access or susceptibility to undetected alteration. Secure communication between individuals, platforms, and command centers has always been an important facet of command and control. The rapid growth in available data from various sensors and unmanned platforms has fueled an insatiable demand for information, filling satellite bandwidth with imagery and full motion video feeds. Military systems – from small devices to large platforms – are increasingly dependent on software for their operation, which in turn imbues these systems with a cyber dimension that can be leveraged and must therefore be protected. As more platforms and devices generate data that can be shared and analyzed – sometimes referred to by the term «internet of military things» (IoMT) – it has become more relevant to focus on secure data communication links. Remotely piloted systems such as aerial drones can be controlled remotely from anywhere in the world via satellite linkages, although the small microsecond delays (or latency) in the system sometimes make it more advantageous to combine satellite communication with physical fiber optic cables.

The current deployment of 5G wireless networks should allow low-latency (from 50 milliseconds down to 1 ms) and high data transfer communication. This substantial increase in capacity, however, comes at a cost. The longer wavelength of 4G has a maximum range of nearly 16 kilometers whereas the shorter high capacity millimeter wavelength of 5G (mmWave) currently has a range closer to four kilometers. Higher frequencies also mean greater attenuation, that is, the signals will be less capable of passing through objects (Horwitz 2020; Huang and Villas-Boas 2020). Secure communication within the cyber domain is more likely when the physical infrastructure is separate from the rest of the global internet. Encrypted communication remains possible but encryption efforts are commensurate with efforts to undermine them: some level of security may hinder the casual or less skilled observer while highly skilled operators may gain access to all but the most securely protected transmissions.

4.1.4 Shoot

The fourth and final function, «*shoot*», includes the various weapons available to engage an opponent via kinetic and non-kinetic fires. The most basic parameters for this include the range of the weapon, the speed at which the engagement occurs, the degree or measure of the weapon's effect, and the level of precision with which an intended target is engaged.[18] A significant development over the past 30 years has been the digitalization of society in many parts of the world. Although a focused attack on a national electricity grid may still be simpler to carry out with a well-placed explosive rather than a highly sophisticated cyber weapon, the ability of individuals or small groups to carry out such an attack without physical access or even geographic proximity is unprecedented. A number of other non-kinetic weapons are also significant, but are less amenable to categories such as speed and range. Chemical and biological agents remain a real threat due to their ability to incapacitate or even kill their targets. Research on bioweapons for defensive purposes has continued, even as legal frameworks and the unpredictable nature and

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[18] While the combined effect of these parameters might also include «lethality», not all types of conflicts will require casualty-focused approaches as a theory of victory. Neutralizing an adversary's platforms and systems (such as armored vehicles, aircraft, missile batteries, or surface vessels) may be adequate to causing defeat and/or achieving the strategic-political goals underpinning the conflict.

therefore questionable military utility of such weapons has limited their use in modern times (Koblentz 2004; Riedel 2004). A far more relevant set of non-kinetic effects are the various ways to manipulate the electromagnetic spectrum in order to disguise, mislead, disrupt, or even damage an adversary's electronic sensors or communication links. These forms of electromagnetic warfare have existed since RF frequency jamming during World War One, but has become far more technologically advanced as military systems rely on digital and EMS manipulation to an even greater degree. Non-kinetic attack using high-frequency microwaves such as the US Active Denial system cause immediate and intense pain without long-term injury, while some type of acoustic or microwave weapon has been suspected in the mysterious spate of illnesses first experienced in 2016 by US embassy personnel in Cuba (Corera 2022; Hambling 2020).

Weapons with kinetic effect have mostly experienced incremental improvements over the past half-century, mostly related to reliability, accuracy, and handling characteristics. A soldier carrying a 1970s vintage AK-74 would not necessarily be at a significant disadvantage against one wielding a modern M4 carbine. Longer-range fires such as artillery, multiple launch rocket systems (MLRS), or tactical ballistic missile systems have undergone a similar incremental developmental history over the past few decades. Portable weapons for use against larger platforms improved with the Javelin anti-tank weapon and the Starstreak portable air defense system in the mid-1990s. Air-to-air and cruise missile technology has steadily advanced as well, with improved speeds and accuracy over the past decades.

Although mobility parameters may be comparable to decades past, modern tanks are qualitatively superior to older models due to significant improvements such as reactive armor, advanced sensors, fire-support guidance systems, gun stabilizers, and incremental ammunition modifications. In the air, improvements such as GPS navigation, better sensors, increased computing power to allow semi-autonomous target identification, and other missile technology have vastly improved long range fires. Surface vessels primarily employ missiles as well to engage airborne threats, other surface vessels, or coastal targets. Subsurface vessels have their own threats with which they must contend, including torpedoes with speeds close to 100 km/hr and a range in excess of 50 km. A final maritime weapon worth mentioning is the stationary yet effective naval mine, with deployment options ranging from submarines to UAVs.

Another class of weapons that has remained relatively unchanged despite some minor refinements are the land, sea, and air-deployed nuclear weapons fielded by the nine global nuclear powers of India, Pakistan, Israel, North Korea, Great Britain, France, Russia, China, and the United States. Variants of these weapons include submarine-launched (SLBM) or land-based long-range intercontinental ballistic missiles (ICBM) capable of carrying a 300 kiloton thermonuclear warhead up to 13000 km within 30 minutes.[19] Land- and sea-based ballistic missile defenses (BMD) have been developed to intercept ballistic missile threats in various stages of flight. Due to their ability to track and intercept warheads during their midcourse phase in outer space, BMD assets such as the Standard Missile 3 have an inherent anti-satellite capability as well.

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[19] By comparison, such a blast is approximately 1000 times more powerful than the Beirut Lebanon fertilizer explosion in 2020, estimated to have a TNT equivalent of 200-300 tons.

4.1.5 Summary of current parameters

Technological developments have occurred regularly throughout history that represented such noteworthy improvements to performance that their effects resonated at the tactical, operational and even strategic level. The most significant advance to mobility came with the integration of the nuclear reactor aboard naval vessels and the advent of the space age. Sensing improved with better use of the electromagnetic spectrum, communication experienced something of a revolution during the digital age, and fires experienced major improvements in range, speed, and precision after the missile age combined with digital communication, better sensors, and GNSS navigation. These were significant enough advances that militaries which failed to take advantage of the new technologies were unable to compete. Some functions – transporting personnel or equipment across terrain or over the sea surface, for example – are unlikely to experience anything other than incremental improvements. Other functions such as communication or sensing may be on the brink of more substantial changes.

4.2 Future warfighting function parameters

Assessing the potential effects of emerging technology on future warfighting functions requires forming a series of assumptions that imagines how future technologies might be employed in a military context. Since military forces tend to be conservative in their adoption of new systems, many of today’s working prototypes remain «emerging» technologies due to the significant and time consuming process of refining, testing, and integrating new technologies into state force structures. Even relatively mature technologies with functional prototypes do not always follow a linear path to becoming force structure elements, and areas with lower technology readiness level (TRL) estimates have an even more tenuous path to adoption. Some technology areas may have uncertain developmental timelines, but a more predictable set of applications that will be rapidly adopted once developed. Other groups of technologies may have a broader and less defined set of potential applications, but have the potential to make a significant impact on warfighting functions if developed and fielded.

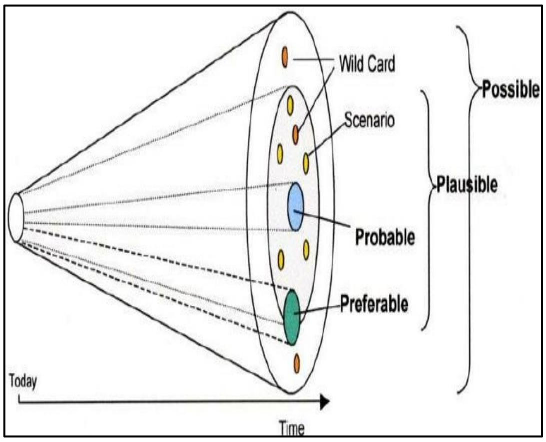

Figure 4.1 The futures cone.

An important facet of foresight analysis is to explore the boundaries of the possible, identify plausible future outcomes, and pose «what if» sorts of questions. We can distinguish between probable EDT systems in the middle of the well-known «futures cone» that have a greater likelihood of appearing in future military force structures, and plausible or possible systems near the edges of the cone that are conceivable but less likely to become functional military systems. This «middle of the cone» versus «edge of the cone» distinction, however imprecise, will be a useful image to have in mind throughout the following analysis to provide an imprecise categorization of future systems. The following sections will assess the impact of potential military EDTs on each of the four warfighting functions, distinguishing between potential incremental and discontinuous effects to parameters such as speed, range, volume, precision, stealth, and robustness. The intent is to explore the most likely scenarios through a «middle of the cone» analysis as much as possible.

4.2.1 Move

A number of emerging technologies may improve the range of individuals, systems and platforms. Human enhancements resulting from advances in pharmacology or genetic engineering that alters physiological attributes related to strength, stamina or sleep patterns could improve a number of basic characteristics of infantry soldiers. For platforms, new materials or manufacturing processes will likely reduce the structural weight (including armor) of ground and aerial vehicles, improving fuel efficiency and therefore range. The electrification of vehicles in the civilian commercial sector appears poised to continue. The practical barriers to purely electric powered armored vehicles currently seem insurmountable, however, not least due to weight and charging issues during operations. Hybrid power looks to be a sensible compromise, providing added range and temporarily silent propulsion. The use of graphene or other advanced materials with unique properties may present new possibilities primarily in the land and air domains. Additive manufacturing processes offer the ability to incorporate multiple complex parts in one printed assembly or the creation of new internal structural designs, both techniques providing significant weight reductions while retaining structural strength.

Autonomous systems having a similar size and payload capacity as their manned equivalent should experience some efficiencies by foregoing the onboard systems needed to sustain and protect a human operator. A new generation of battery technology that improves on lithium ion batteries might allow for greater and more efficient energy storage. A vehicle's frame might even be composed of energy storage material able to fully recharge within minutes through wireless power transfers, dramatically increasing the range and functionality of autonomous systems. As space travel and exploration enters a new «golden age», space stations and lunar colonies may provide advantageous launching pads to destinations farther afield and avoid the energy-intensive trip through the earth's atmosphere and the planet's gravitational pull.

Although range may experience incremental improvements, volume is another story. Expensive and highly capable multifunctional platforms have tended to dominate state acquisition policies. More mission-specific autonomous systems, due to potentially lower production costs and the scalability of operational software, are expected to increase the number of fielded systems in all the physical domains as well as cyberspace. These systems may be sufficiently affordable such that greater numbers can be fielded and therefore be considered more «attritable» or expendable than human-operated platforms. Coupled with machine learning algorithms, swarms of autonomous systems will be able to function as one coordinated entity to accomplish a given mission set. Large satellite constellations may vastly improve coverage and robustness of space-based sensors (Andås 2020, 45). New space stations or even a base on the lunar surface would enable extended missions outside the earth's atmosphere (David 2019; Jones 2021).

Speed is another decisive aspect of mobility and creates advantages at the tactical, operational and strategic level. Modern military forces use technology to gain these advantages not only in the physical domains but also in the digital and cognitive spheres. Advances in quantum computing hold the promise of exponential increases in computing speed in the cyber domain, with second order effects in many other aspects of military operations and technological innovation as a whole. Hypersonic vehicles such as boost-glide vehicles and cruise missiles are primarily weapons better categorized under the warfighting function «shoot», but scramjet technology utilized in larger reusable hypersonic aircraft may alter air mobility – particularly if sensor technology reduces the low radar observability of «stealthy» aircraft and speed becomes a substitute for stealth (Amos 2022).

Operating without detection has become challenging as sensor technology improves and proliferates. Managing electromagnetic signatures is an important aspect of modern warfare. In the future, as sensors become even smaller, more capable, and more plentiful, competition in the electromagnetic spectrum will become even more intense. New materials that better absorb and/or manipulate electronic or acoustic signatures – even to the point where referring to them as «cloaking» materials becomes meaningful – may offer new tools in the competition between «seekers» and «hiders». Precision navigation often relies on satellites, but this precision may not always be available if an adversary successfully interrupts or interferes with satellite signals. Even without this disruption, activities underwater or underground may be more advantageous to escape the watchful eyes of satellites. Quantum precision navigation and timing (PNT) that includes quantum gyroscopes, quantum clocks, and accelerometers could offer extremely precise GNSS-independent navigation.

Do these advances promise discontinuous technological innovation or simply incremental change for battlefield mobility? For vehicles, hybrid drives and lighter materials will likely improve mobility or reduce detection incrementally. A similar situation exists for human enhancement technologies. These are important improvements, but as O'Hanlon concluded: «it remains unclear how much difference they will really make if combatants on all sides of a given conflict all have access to relatively comparable performance enhancers. Nor will any of the foreseeable advances make comic book heroes out of soldiers» (O'Hanlon 2018, 26). If developed, hypersonic aircraft constitute a substantial capability that can have significant impact on operations, particularly if speed can act as a substitute for stealth in a quantum radar environment. Space exploration and satellite technology will continue to improve, but perhaps not dramatically so. Quantum PNT and the potential for significant signature reduction through materials and electromagnetic manipulation will allow more precision navigation and stealth, but these improvements will likely be felt only at the margins. Mobility in most domains – particularly with regard to transporting personnel and equipment over the earth's surface – will experience only incremental changes over the next several decades, with two important exceptions.

Discontinuous change will almost certainly be felt in the cyber domain if practical and reliable *quantum computing* solutions are developed, due to the massive increase in computing power and speeds, and the potential convergent effects this will have on artificial intelligence. In the physical world, groups of *autonomous platforms* acting in coordinated swarms in the air or at sea will alter the volume of platforms operating on the battlefield and influence ISR capabilities, strike options, and logistical solutions as information gathering, lethality, and vulnerability are able to be distributed in a cost-effective way. Actors that successfully exploit this possibility in a cost-effective manner will have a significant advantage over those with limited numbers of exquisite systems. Even if most actors invest in significant numbers of autonomous systems, tactical engagements are likely to occur so rapidly that the actors with superior algorithms controlling these systems are likely to prevail. Of course, an advantageous cost exchange ratio defense against UAVs or USVs such as directed energy or electromagnetic pulse (EMP) solutions may dampen this trend, causing «hardening» requirements to increase the cost of autonomous systems.

4.2.2 Sense

Future developments regarding information collection on the surrounding environment have often been closely linked to advances in data processing and advanced analytics of large data sets, particularly given the increased quantity and quality of sensors and sensor data. This will significantly influence the range, volume, and precision of sensors over the next several decades, as these three closely related aspects of sensing generate multiple feedback loops. In the oceans, improvements in data analytics and signal processing may greatly increase the range and sensitivity of both passive sonar capabilities and low-frequency synthetic aperture sonar (O'Hanlon 2018, 8). The curvature of the earth has long been a limiting factor for surface radars, but the new generation of Over-the-horizon (OTH) radars and ground-based Passive Coherent (PCL) radars may significantly extend current detection ranges by a factor of four (Reding and Eaton 2020, 42,82).

The likely quantitative increase in sensors – from unmanned platforms to inadvertent internet-enabled civilian sensors able to be accessed as needed – will indirectly influence the range and precision of information gathering. With the merging and evolution of nanotechnology and wireless technology, extremely small sensors or «smart dust» may offer highly detailed yet less detectable information about a local environment. Other small sensors may be attached to clothing, armor or other material to provide data on physiological, biological or environmental status of soldiers and their environment (Reding and Eaton 2020, 96). Space sensors will not only look downward to observe activities on the Earth's surface, but will increasingly peer outward as well – establishing space situational awareness by monitoring space-based objects and activities. Volume is a relevant parameter in space, with future large constellations of low-cost satellite sensors in LEO and MEO that offer better coverage, precision, and more flexibility (Reding and Eaton 2020, 77–80). In the digital sphere, AI is already in use to monitor networks for abnormal activity that might signal unauthorized intrusions. Advances in AI and the potential for powerful quantum computing abilities might allow for even better algorithmic monitoring tools to gather and analyze digital networks.

Once again, quantum technology appears poised to shift the boundaries of what may be possible for radar systems – at least in theory (Andås 2020, 50). Substantial disagreement about the potential performance and implications of quantum radar complicate projections about the future of sensing. A 2019 Defense Science Board concluded that the technology would not improve detection capabilities, while a 2018 Chinese announcement claimed that a prototype quantum radar system was able to detect very stealthy aircraft (Krelina 2021; Reding and Eaton 2020, 72; Tingley 2021). The first statement might indicate relatively modest improvements from quantum radar, while the second could represent a significant discontinuity for air power in the 21st century.

In sum, sensors in all domains will experience substantial albeit incremental improvements in range, precision, and coverage. The physical properties governing the behavior of wave forms in the electromagnetic spectrum remain constant, but our ability to manipulate and interpret these signals may improve dramatically. The most probable «middle of the cone» future includes substantially better sensors without any discontinuous improvements, but an «edge of the cone» possibility of discontinuous innovation regarding a post-stealth *quantum sensor* era should also be considered.

4.2.3 Communicate

We are currently experiencing a significant – albeit incremental – evolution in military wireless communication that will eventually create an integrated, networked system able to transfer data relatively seamlessly and with low latency across an Internet of Military Things (Gill 2022). Similar to the other functions discussed here, a number of emerging technologies are on the cusp of becoming operational capabilities. They are «emerging» in the sense that even a proven technology still requires infrastructure, operational concepts, and integration into national force structures. These processes often take years until the benefits of a system are fully realized, and sometimes are discarded along the way if institutional support is lost and/or it is discovered to not be as beneficial or cost-effective as originally anticipated (Pernin 2012).

These two technologies – wireless communication and IoMT – appear to offer unique tactical and operational advantages if fully developed, and will improve the volume of data able to be transferred at greater speeds and better security than is currently possible. The possibilities of UAS as communication relays or mesh networks available today will be significantly enhanced with improvements to wireless communication, increased energy storage capacity, new materials that provide more advantageous size, weight and power (SWaP) characteristics, and more advanced machine autonomy software. With increased numbers and greater endurance, multiple communication nodes can operate well beyond line of sight and maintain the network even if several individual platforms are lost. The continuous competition across the electromagnetic spectrum will likely intensify as networks grow in importance, with adversaries seeking to disrupt or intercept data being shared across the network.

The robustness of data communication relies not only on the physical properties governing connectivity but also adequate encryption that prevents adversaries from intercepting messages. Quantum key distribution (QKD) currently provides secure linkages over short distances and potentially for longer distance secure communication using a space-based satellite repeater, as China has demonstrated (Kwon 2020). Given the anticipated power of quantum computing and its ability to crack some of the mathematically based encryption techniques, new «post-quantum» encryption methods will be necessary (Krelina 2021, 12–13; Vermeer, Parker, and Kochhar 2022).

The digitalization of communication has presented new challenges as well. Credible yet false digital content can be relatively easily created using an AI technique known as Generative Adversarial Networks (GAN), a method for generating artificial data sets to train and develop machine learning algorithms. These so-called «deep fakes» are currently more of a novelty than a threat, but future iterations that are indistinguishable from their originals may be more troublesome as adversaries generate false voice and video content (Hwang 2020). Propaganda is a well-known component of human conflict, but the digitalization and globalization of media – and the popularity of social media in particular – introduces new and powerful tools of influencing populations, obfuscating the truth, and hindering a collectively agreed-upon set of facts.

In particular, the use of algorithms to analyze typical human responses to stimuli in order to hold the attention of target audiences, whether to continue using a particular media platform or microtargeting for advertisers, has proven to be a powerful tool that can be wielded for profit or public opinion manipulation (Duhigg 2012; Perl 2019). In a military-strategic context, some have called this approach «cognitive warfare», where information operations are waged to influence perceptions and political support (Ottewell 2020). In our increasingly digitalized society, powerful algorithms using large amounts of available personal data will likely be able to effectively and surreptitiously manipulate public opinion (Paul and Posard 2020; Singer and Brooking 2018).

Another communications link that may offer new possibilities are brain-computer interfaces (BCI), particularly with the growing role of autonomous systems in military operations. Commercial ventures and defense related investments focused on understanding, interpreting, and utilizing brain activity are currently using the electronic signals generated by the brain to communicate with and/or control external devices. Potential applications include neural interfaces that allow human thoughts to flow directly to machines or computers (brain-machine interface or BMI) for enhanced human-machine cooperation, direct control of drone swarms using wireless brain connections, or even direct non-verbal human-to-human communication via wireless neural links (Binnendijk, Marler, and Bartels 2020).

The incremental changes taking place in wireless technology are likely to support new possibilities in networked operations, although uncertainties remain with regard to size, range, and resistance to disruption. Within the next two decades, another generation of wireless technology will likely emerge with even greater data capacity and reduced latency. The *networked IoMT*, having solved many of the architectural and doctrinal issues using a 5G network, will then be able to reap the full advantage of distributed military operations. The development of autonomous systems operating in a coordinated manner with humans on a robust wireless network would constitute a discontinuous technological development, but this discontinuity will evolve over time. The incorporation of *BCI/BMI* technologies into this architecture would constitute an even more pronounced discontinuity, given the synergies and tactical agility that might result from autonomous swarms directly controlled by the human mind.

4.2.4 Shoot

Incremental improvements are likely for most types of effectors, with a few potential disruptive developments. Steady improvements in small arms and portable anti-platform weapons are likely to continue. However, small autonomous swarming effectors may constitute a potential change at this level, building on current small loitering munitions such as the Aerovironment Switchblade. Data processing at the «edge» continues to decrease SWaP requirements, the adoption of new materials and energy storage techniques will improve small UAV endurance, while new AI-specific microchips increase the speed and efficiency of algorithmic «decisionmaking». Combining smaller tactical UAVs with smart loitering munitions will allow autonomous sensor-shooter combinations for perimeter defense or offensive tactical operations (Atherton 2021). In doing so, autonomous swarms will greatly increase the volume and precision of fires that small tactical units are able to direct towards an adversary.

Another relevant (and existing) emerging technology for effectors is the class of weapons known as hypersonics, including cruise missiles (HCM) and glide vehicles (HGV). Recent developments by Russia, China and the United States have demonstrated the viability of the various concepts, which will likely be fully developed and fielded over the next decade. Russia reportedly fired between 10-12 Kinzhal hypersonic air-launched ballistic missiles during its 2022 invasion of Ukraine (Copp 2022). Although ballistic missiles also reach hypersonic velocities during reentry, hypersonic vehicles have the potential for much greater speeds that reduce flight times by as much as 50-75%. Significantly, HGV combine this speed with maneuverability as they approach their targets. This poses significant technical challenges for interception by defensive systems and political and military leaders faced with a severely truncated decision space. Even so, it remains unclear whether hypersonics represent a discontinuous technological advance or simply constitute another potent and expensive weapon in state military arsenals.

An emerging technology with the potential to counter drone swarms and possibly even hypersonic missiles are directed energy weapons (DEW), including high-energy lasers, high power electromagnetic (HPEM) weapons, and possibly even space-based particle beam weapons (Air Force Research Lab 2021). Directed energy weapons will potentially significantly improve the volume, precision and speed of engagements. Against UAVs or cruise missiles, DEW have significant advantages in terms of engagement speeds and cost-exchange ratios. The SWaP requirements for generating a sufficiently lethal beam have improved significantly over the past two decades, making directed energy weapons more practical. Currently, a 50-kilowatt high-energy laser weapon can be mounted on an infantry fighting vehicle, constituting an adequately powerful beam to engage several dozen small UAVs at over 1500 meters, given a several second engagement time and short re-engagement phase between targets (Eversden 2022; Lippert 2021, 12). One report concluded that over the next 40 years, powerful lasers of several hundred megawatts may decrease engagement times down to milliseconds, making DEW faster than kinetic weapons (Air Force Research Lab 2021, 21). Increased beam intensity and reduced SWaP requirements will make laser weapons even more practical for vehicles, aircraft, and surface vessels, challenges posed by turbulence and atmospheric conditions notwithstanding.

Non-kinetic weapons may become even more relevant due to more powerful AI tools, quantum computing, and biotechnology. With a greater emphasis on software and digital infrastructure within networked military systems, cyberweapons are likely to become even more relevant in the future. Due to the inherent secretive nature of these capabilities and the fact that code is less visible than an armored vehicle, cyber tools are more challenging to observe and analyze but appear poised to be even more powerful. Biological and chemical warfare have a well-deserved notoriety due to the particularly gruesome effects of these capabilities, their tendency to be unleashed on civilian populations, and the difficulties in wielding them in a controlled and militarily useful fashion. Synthetic biology and genetic engineering may change this equation if certain pathogens can be modified or synthetically designed to be directed against individuals or groups of adversaries with a specific set of genetic markers, enabling tailored bioweapons that potentially solve the problem of control (Biberman 2021; Knutzen 2021).

In sum, there appears to be a significant degree of continuity and incremental development regarding kinetic options for engaging an adversary. One exception to this are *autonomous swarms* of unmanned systems that offer a far greater quantitative volume of effectors in engagements. A second technology, *directed energy weapons*, potentially offers a defensive counter to swarms as well as a potent offensive weapon that increases the speed, volume and precision of fires. Synthetic biology is the final technology presenting a unique effector in the form of tailored and (ostensibly) controlled *bioweapons*. Due to the significant changes to fundamental parameters such as speed, volume and precision, these three systems should be considered «discontinuous» in nature.

4.2.5 Summary of future warfighting systems

Emerging technologies will alter the parameters of military operations. The extent to which these parameters change and the consequences of that change are far less certain. The integration of new technology into existing and novel military systems drives innovation forward in a process of continual improvement and progress. Whether these improvements constitute a noteworthy yet qualitatively incremental improvement, as opposed to a substantial discontinuous one, may ultimately be a subjective evaluation. Based on the preceding discussion, at least eight future systems have the potential to effect discontinuous change on the four warfighting functions evaluated in this report. For mobility, autonomous systems in all domains can – depending on the domain and application – significantly affect the range, speed, and volume of systems at the tactical and operational level. In the air domain, some type of quantum sensing can have a discontinuous effect on the ability to detect stealth aircraft. Seamless communication between systems and entities in a comprehensive military network or Internet of Military Things is likely to greatly enhance the range, speed, and volume of communication. Brain-computer interfaces are likely to substantially improve communication between humans and machines in all domains. For effectors, autonomous swarms (primarily in air and sea domains) will increase the volume of fires, synthetic bioweapons present a dangerous new level of volume and precision, while directed energy weapons may be useful direct fire capability and a defense against UAV swarms as they influence the speed, volume and precision of future «shooters».

Function	System	Primary domain	Parameters affected
Move	Autonomous systems	All	Range, speed, volume
	Quantum computing	Cyber	Speed, volume
Sense	Quantum sensing	Air	Precision, range
Communicate	Networked IoMT	All	Range, speed, volume
	BCI/BMI	All	Speed, volume
Shoot	Autonomous swarms	Air, Sea	Volume
	Directed energy weapons	Air, Land, Sea, Space	Volume, speed, precision
	Synthetic bioweapons	Land	Volume, precision

4.3 Future force structure vignettes

Decisions about a state's military force structure are complex and do not necessarily adhere to a structured linear process governed by rationality or logical cost-benefit calculations. Internal factors such as national symbolism and pride, budgetary concerns, interservice rivalries, local political dynamics, business interests, or alliance relationships influence force structure choices alongside professional military expertise on matters such as operational effectiveness, lethality, or force protection (Adams and Williams 2010; Sarkesian, Williams, and Cimbala 2008). Changes to a state's strategic focus – whether inspired by external shifts or internal re-prioritization – can influence force structure choices over time. An important – if not the most important – factor that influences a state's future force structure is the state's current force structure. Military systems are expensive and costly to modernize or replace. Since most states have budgetary constraints and existing materiel creates path dependencies, actors rarely have the flexibility to acquire an entirely new set of force structure elements over a 20–30 year period.

These force structure design considerations also complicate the relationship between the emergence of discontinuous technologies and their acquisition by state actors. In general, we can assume that decision makers are most interested in acquiring the greatest performance improvements with regard to warfighting functions, combined with the lowest financial burden and fewest integration challenges. It may be logical to assume that state leaders are interested in acquiring military systems with the potential for discontinuous effect, either to gain a first mover advantage over potential rivals or simply to avoid falling behind technologically. The decision to develop and deploy quantum sensors, brain-computer interfaces, or directed energy weapons are nevertheless based on far more than a pure military cost-benefit logic. Emerging technologies will influence other critical functions than those discussed here, and those functions will influence the performance of force structure elements.

This report focuses primarily on the effects of military technology on future force structures. The following pages are an attempt to combine the analysis of each state's force structure and innovation focus together with the potentially disruptive technologies discussed in this chapter. Clearly, a multitude of additional factors influence national decisionmaking regarding the size and shape of military forces, including geopolitical, economic, demographic, and societal trends. The effects of climate change – including the cost of mitigation efforts or even the effects of technological solutions such as geoengineering – can also have a substantial impact on these and other variables (Litan 2022). Many non-technology related assumptions must therefore go unacknowledged when creating a coherent composite image of force structures. What follows are a series of brief vignettes imagining the possible force structures of Russia, China, and the United States in the year 2050. These are all possible force structures with varying degrees of probability. They are offered here as futuristic creation stories and will be used in further work that explores future operating environments.

Vignettes and futures analysis

Identifying trends in technology development and military thought are important facets of strategic foresight analysis, but exploring the possible implications of these trends requires a deeper understanding of the future. By fusing current trends with likely developments based on inference and a healthy dose of creative license, we can create fictive future situations that allow us to gain a more holistic view of potential futures. These vignettes are not meant to be an accurate prediction or portrayal of the future. A coherent fictional description simply serves as an analytical tool that allows us to visualize future developments, deepening our understanding of potential interactions between trends and the indirect effects that are likely to result.

4.3.1 Russia: an optimistic rebuild

Russia's 2022 invasion of Ukraine in February severely hampered the country's military cohesion, economic prospects, and its defense industry. The amount of expended, destroyed, or abandon military equipment alone numbered in the thousands. Replacing these systems proved to be an expensive proposition, made even more difficult due to international sanctions that limited Russian economic activity along with access to raw materials and components needed for its defense industry. Ultimately, however, the conflict spurred reinvestments within Russia's domestic industrial base. Out of pure necessity came the development of previously imported key technologies and materials, including the lithography machines that reinvigorated Russia's dormant microchip manufacturers. Even so, many of the factors that previously limited military innovation efforts have remained, including bureaucratic inefficiencies, corruption, limited civilian-military technology research transfers, quality control issues in production, and a «brain drain» of highly skilled technology researchers.

Russia began 2023 as a politically isolated country with a severely weakened military, an economy in shambles and an unstable domestic political regime. A series of difficult choices slowly put the country back on a steady yet slow path to recovery. Russia's armed forces in 2022 contained significant numbers of modernized versions of older, Soviet-era equipment in its land and maritime components, many with replacement systems already developed and ready for production. With its slowly revitalizing defense industry, new systems began production runs despite their markedly lower quality compared to Western systems. Among the emerging military technologies emphasized by Russian political leaders in statements and documents, artificial intelligence, autonomy, quantum technologies were among the most prominent. Capabilities that sought to manipulate the electromagnetic spectrum remained a priority for the Russian military, particularly given its military doctrine emphasizing advanced technologies as an asymmetric counter to Western military advantages. These were not prominently displayed during the Ukraine conflict, but become more relevant again as Moscow sought to better integrate emerging technologies into its force structure. Doctrinal discussions and attitudes reflect an ambition of leveraging technology in an asymmetric fashion, with a particular focus on cyber operations, information warfare, and utilization of the electromagnetic spectrum. Bioweapons featured prominently in Russian R & D throughout the 2030s, given the lower production costs and the new-found ability to tailor these weapons in ways that made them more operationally useful.

Defying expectations, Russia's force structure therefore appears reasonably capable in 2050. Russian land forces now operate several thousand modern and redesigned T-14 hybrid drive MBTs with domestically sourced electronics, in addition to thousands of older refurbished MBTs and IFVs converted into optionally manned systems. Artillery pieces and MLRS systems produced in the 2030s to replace those lost in the Ukraine conflict are semi-autonomous platforms with several small organic integrated aerial drones to identify and track surface targets. Without a feasible option to produce sufficient quantities of complex exquisite systems, the military leadership has invested in large numbers of inexpensively produced autonomous systems tied together with a robust xG high capacity wireless network (several iterations after 5G and therefore designated xG). Medium-sized autonomous ground vehicles operate alongside the heavier MBTs, acting as «wingmen» that provide additional munitions as well as extra protection for the manned platforms, using electronic warfare and kinetic means to defend against adversarial drone swarms. Armored cavalry personnel use a rudimentary brain-computer interface (BCI) to control some vehicle features, in addition to the AR helmet providing situational awareness. Infantry soldiers are «hyper-enabled» with multiple genetic improvements and integrated AR heads up displays.

At sea, the country's littoral defenses are secured by a sizeable fleet of autonomous corvettes and semi-autonomous mini-icebreakers, powered by domestically produced microchips of variable quality with new battery technology developed at the Era campus and armed with long-range anti-ship cruise missiles and surface-to-air missiles. These smaller vessels patrol continuously in the northern (mostly) ice-free waters of the Arctic along with manned frigates and modern attack and strategic submarines. In the air, Russia has applied their expertise in electromagnetic manipulation to UAVs. A similar concept exists for the substantial fleet of Su-57 fighters that operate seamlessly with their autonomous UAV counterparts. Older airframes have been converted to decoys that lure an adversary's air defenses to reveal themselves. Novel materials and additive manufacturing techniques have enhanced the low-observability characteristics as well as substantially reduced the unit cost of UAVs and missiles – another lesson from the Ukraine war. In space, Russia's capabilities are limited but not entirely absent due to the lack of resources to conduct sufficiently advanced R&D. In lower earth orbit, Russia nevertheless maintains numerous ISR resources but has ceded this domain largely to China and the United States.

Notional Russian force structure 2050	
Land	• Hybrid armored vehicles with traditional armaments plus EW for C-UAS, operators using neuralink BCI • Substantial numbers converted "optionally-manned" ground systems • Range of UGV with xG connectivity • Hyper-enabled soldiers with AR/HUD • Prominent role for tailored bioweapons
Sea	• Traditional littoral surface vessels combined with USV/UUV, armed with long range missiles • Traditional submarine and surface vessel fleets integrated with other manned and unmanned air, space, sea assets
Air	• Legacy 5th Gen aircraft combined with attritable UAVs fleets for ISR/attack/EW in swarms and CCA configurations, also use as inexpensive decoys • Pilots with first gen BCIs and AR rigs
Space	• Limited presence – nanosatellite constellations for communication, ISR
Cyberspace	• Comprehensive set of AI-enabled offensive cyberweapons
Doctrine	• Emphasis on deterrence and disruption using nuclear weapons and non-kinetic tools such as EW and cyberweapons • Doctrinal focus on domain integration, UxV swarming with kinetic fires, seventh generation warfare

Russia struggles in the mid-21st century to sustain the level of technological development necessary to compete with the United States or Europe, but has managed to produce viable alternatives despite its political and economic isolation. Its force structure has become even more oriented towards defending its existing territory. Therefore, the technologies most emphasized are those with the greatest deterrent and disruptive value for the lowest possible investment: nuclear weapons, autonomous systems, and AI-powered cyberweapons. Established nuclear technologies can be further refined with the help of artificial intelligence and the next generation of software that models explosions down to the molecular level. Researchers have developed tailored bioweapons that incapacitate rather than kill their targets in order to overwhelm an adversary, thus presenting them with a highly credible threat. Newer missile and autonomous systems in the air, at sea, and on land are designed to intercept and disrupt an adversary in a cost-effective manner.

Russia's force structure in 2050 represents a mix of modern manned platforms with autonomous support systems in a traditional «force multiplier» role. The reduced personnel requirements have allowed for a smaller and better trained force with years of experience conducting field exercises in algorithmic warfare alongside their autonomous counterparts. Long-range kinetic fires are still considered necessary but as a supplement to EW, cyberattacks, and novel counter-AI tactics to confuse and neutralize an adversary's military systems. These non-kinetic means have become a decisive element in the «Russian way of war». Russian defense industry actors have failed to compete with other national champions in quantum computing, and design processes have suffered as a result. Force structure elements rely less on qualitative parity and more on quantitative advantage and swarming tactics, along with decoys and spoofing. Given the significant challenges that Russia has faced over the past thirty years, leaders consider this relatively technologically advanced military to be a «best case» outcome that even the most optimistic analysts would not have predicted back in 2022.

4.3.2 China – a continued acceleration

Compared to the Russian case, the Chinese have enjoyed a far more advantageous set of national characteristics that made the country well positioned to support an ambitious program of defense innovation over the past three decades leading up to 2050. Just as the 1991 Gulf War may have inspired China's leaders to modernize their military forces, the 2022 Russo-Ukrainian war impressed upon them the importance of operational experience, logistical planning, and the value of a domestic defense industry that is not reliant on foreign components for the production of military materiel. With its domestic political leadership firmly in control, China demonstrated foresight and strategic patience by making long-term investments in necessary infrastructure and R&D to develop future military systems enabled by emerging technologies. Military budgets remained high despite an economic slowdown in the 2030s, increasingly burdensome and costly climate change mitigation efforts, and internal domestic crackdowns to maintain political control. Concerns by analysts in the 2020s focused on an aggressive «peaking» China might be forced to act on its regional ambitions before succumbing to structural weaknesses, or contribute to a regional conflict bought on by the inherent friction of a rising power challenging the declining hegemon (the so-called «Thucydides trap») ultimately proved to be unfounded as China surged ahead (Economist 2022a).

The continued strength of China's manufacturing base has supplied the country with the economic wherewithal to continue its military modernization program, with annual defense budgets averaging over US$250 billion. State planners successfully leveraged the strong industrial base and a state-managed innovation effort that combined the discipline of a top-down approach with the flexibility and technological cross-pollination of the civilian sector. The emerging technologies prioritized by China's research sector have been similar to other states, including AI, autonomy, quantum technologies, biotechnology, and hypersonics. In addition, research into energy generation and storage has been particularly prominent. The organizational and doctrinal approaches discussed in open sources appear to have been an appropriate match for new systems utilizing emerging technologies. The «Intelligentized» warfare approach accommodates autonomous systems, the application of artificial intelligence, and advanced data processing and quantum computing. The authoritarian regime in Beijing has utilized AI technologies such as social monitoring and facial recognition for widespread societal surveillance, thereby harvesting large amounts of data and experience that proved useful for military applications.

China’s force structure in 2050 is comprised of modern technologically-advanced systems in all domains. Modernizing the world’s largest standing army has been a substantial and uneven process, given that a significant portion of the PLAA’s armor was in need of upgrades. Autonomy has become an important feature of the country’s ground forces even though its strategic focus has been predominantly on air and naval power, which were the domains most amenable to autonomous systems. Despite being underfunded compared with other service branches, the PLA Army remains the world’s largest fighting force.

After years of experimentation with human-machine teaming, the Chinese developed an effective BCI based on a neural implant that captures the electrical impulses from the cerebral cortex. AI-generated research using quantum computing quickly found the proper genetic sequencing to create genetically enhanced personnel with greater cognitive capacity to process information and interact with machines via the neural link. As a result, armored vehicle operators have a holistic view of the battlefield with their AR rigs and provide thought-commands to the autonomous ground and aerial systems in their tactical groups via an xG wireless network. The autonomous systems range from defensive C-UAS laser weapon units to small four-legged sensor scouts that operate in a perimeter around each armored unit to provide early warning of adversarial movement and potential anti-tank munitions. Autonomous systems are powered by solid-state graphene batteries that are quickly charged by a special purpose tracked vehicle. Behind the armored phalanx, hyper-enabled ground forces have extremely lightweight body armor and a helmet-mounted heads-up display providing tactical situational awareness.

Building on its fleet of fifth generation fighter and attack aircraft, the PLA Air Force has added large numbers of UAVs, leveraging advances in autonomy with a similar human-machine teaming concept rather than pursue a sixth generation human-piloted aircraft. Pilots with AR rigs and BCI implants act as «managers» for small groups of autonomous aircraft operating around it that can independently identify and target an adversary’s air defenses and counter-air capabilities. For certain missions, autonomous swarms can be used to directly target all military systems in a designated geographic area, with a human commander overseeing – although not directly controlling – their movements. Using new materials and advanced algorithms, piloted and autonomous aircraft emit signals designed to confuse the first generation quantum sensors systems of the United States, while its second-generation systems are more adept at detecting and tracking stealthy aircraft. The combination of AI and quantum computing has allowed Chinese cyber personnel access to a range of new offensive cyber weapons that it wields in all levels of military operations. Advances in genetically altered and tailored bioweapons, enabled by a convergence of AI, quantum computing and synthetic biology, gives China another non-kinetic and asymmetrical capability.

Beijing’s nascent space program has expanded to make China the leading power in outer space, having invested large sums in the «ultimate high ground». Chinese hunter-killer satellites are a constant threat to an adversary’s space-based sensor and communication platforms while protecting their own, stalking LEO with EW disruptions or kinetic strike options in clear violation of the hopelessly outdated 80-year-old Outer Space Treaty. China’s construction of several large space stations in low earth orbit have provided an advantageous logistics hub that offers exceptional space situational awareness and acts as a space-based «aircraft carrier» for operations. Having already provoked the international community by establishing a «research» facility on the Moon, the PLA has used this foothold as a bridgehead to better control cislunar space.

Notional Chinese force structure 2050	
Land	• Hybrid armored vehicles with traditional and HEL for C-UAS, operators using neuralink BCI • Range of UGVs with solid state batteries and xG connectivity • Hyper-enabled soldiers • Tailored bioweapons
Sea	• Traditional aircraft carriers + smaller short deck carriers with UAV wing, serves as floating charging station for USV, UUV, UAV, defended by missile/HEL • Traditional submarine and surface vessel fleets integrated with other manned and unmanned air, space, sea assets
Air	• Legacy 5th Gen aircraft combined with attritable UAVs fleets for ISR/attack/EW in swarms and CCA configurations • Pilots with BCIs and AR rigs
Space	• Substantial presence with multiple “carrier” space stations and satellite constellations • Logistical base on lunar surface • Space-based kinetic weapons
Cyberspace	• Quantum-enabled cyber tools for design of military technologies • Comprehensive set of AI-enabled offensive cyberweapons
Doctrine	• Newer version of «Intelligentized» warfare emphasizing domain integration, rapid decisionmaking with AI in decisionmaking loops

The combination of inhabited and autonomous air and space platforms provides China with a fairly unobstructed view of the Asia-Pacific region, its primary strategy focus. China’s massive ship-building effort throughout the early 21st century resulted in a sizable fleet of small and medium-sized vessels for the littorals, several new aircraft carriers with a mix of manned and unmanned platforms, along with several types of submarines. Its blue water navy rivals that of its closest competitor, the United States. After the completion of its third aircraft carrier, the PLA Navy shifted its focus to the construction and acquisition of a class of smaller, highly automated 200-meter amphibious assault ships that act as floating bases and charging stations for UAVs, smaller USVs and several UUVs. The highly networked maritime force is seamlessly joined to air and space assets, using the situational awareness gained from large numbers of autonomous sensors to act more quickly and decisively in a true multi-domain fashion. With defensive directed energy systems and intelligent missile swarms to outmaneuver and overpower an opponent’s vessels, the Chinese Navy deploys throughout South Asia to support its political allies, police shipping lanes, and intimidate rivals.

China's force structure in 2050 reveals a strong preference for efficiency, automation, and control. Cutting edge research in neuroscience, quantum technology, and autonomy has produced a series of robotic systems that take advantage of the information dominance provided by their shared network, while remaining agile enough to adapt when information is incomplete. Their overarching «way of war» is to use humans principally as support personnel and enablers for autonomous platforms that are less expensive, more agile, and more politically reliable.

4.3.3 United States – maintaining a dwindling lead

Regarding future force structures, the United States differs from Russia and China in several important respects. Unlike the other two states which are best categorized as regional powers, the American military is an expeditionary force capable of global power projection with global commitments to a multitude of allies and partners. In addition, the US remains a free-market democracy with a strong commercial sector and relatively robust industrial base. This global influence provides opportunities for security partnerships and defense exports, while the strong civilian defense manufacturing base draws on inspiration and technical know-how from both the civilian and military spheres.

The US force structure in 2050 ranks as the world's most capable, rivaled only by China. Maintaining readiness throughout such a sizeable force represents a significant expense, but steadily renewed force structure elements throughout the 2020s positioned the military well for future acquisitions. Clear-eyed prioritization and a motto of «divest to invest» inspired by the US Marine Corps approach allowed the services to devote funding to newer systems rather than a recapitalization of the existing force. By 2050, the US fields a new version of its main battle tank, large numbers of ageing 5th generation aircraft augmented by limited numbers of 6th generation aircraft, multiple classes of unmanned systems, refurbished surface ships, new attack and ballistic missile submarines, and a C2 network fusing these elements together. One of the most costly projects, the Ford-class aircraft carrier with a procurement cost of nearly US$13 billion, was expected to replace the current carrier fleet on a one-for-one basis but those plans were eventually discarded. These large, complex and costly platforms were deemed too susceptible to disruptive technological changes, and other concepts proved more viable. In general, however, the existing force structure provided a solid foundation to which new EDT-enabled elements were added.

The diverse set of missions US forces have been tasked to perform required a substantial operating budget, but provide a broad array of entry points for promising emerging technologies to be integrated into new force structure elements. This has been assisted by a strong defense industry and a broad R&D portfolio that leveraged the efforts of technology companies creating products for the civilian market. The military doctrines under development during the 2020s reflected an ambition to actively pursue the benefits of wireless communication, data processing, autonomy, and other EDTs into a multi-domain framework for joint operations. Quantum computing and synergy effects with AI resulted in several radically new platform designs and better capabilities in cyberspace. This has served to maintain the US lead in military innovation, apart from a few key areas in which American industry has fallen short relative to their Chinese counterparts – such as the greater regulatory burdens associated with biotechnology.

Notional US force structure 2050	
Land	• Hybrid armored vehicles with traditional armaments + HEL and EW for C-UAS, combined with a range of tracked and quadruped UGVs with solid state batteries and xG connectivity • Hyper-enabled soldiers with next-gen AR/HUD
Sea	• Large aircraft carriers with legacy fighters and UAV wings • Mixed fleet traditional surface vessels and USV/UUV, all with long range missiles and HEL ship defenses • Traditional submarine and surface vessel fleets integrated with other manned and unmanned air, space, sea assets
Air	• Legacy 5th Gen aircraft and some 6th Gen aircraft, combined with attritable UAVs fleets for ISR/attack/EW in swarms and CCA configurations • Pilots with next gen AR rigs
Space	• Moderate presence – significant satellite fleet (incl. nanosat constellations) for communication, ISR • Nascent space-based anti-sat capability • Lunar logistics base
Cyberspace	• Quantum-enabled cyber tools for design of military technologies • Comprehensive set of AI-enabled offensive cyberweapons
Doctrine	• Newest iteration of JADO-mosaic warfare with domain integration and AI in decisionmaking loops.

The US deploys a modern and technologically advanced force structure in the mid-21st century. The move towards optionally-crewed systems in the physical domains gave way to smaller autonomous systems as machine intelligence performance improved. On land, UGVs of varying size escort crewed armored platforms, providing extra sensor data, detecting potential threats and targets, and providing directed energy defensive capabilities against missiles and UAVs. Infantry have helmet-mounted heads-up displays and access to a wealth of battlespace information, but not genetic modifications or BCI capabilities like their Chinese counterparts due to ethical and legal considerations. Ground-based quantum sensors greatly enhance precision, such that the combination of surface and space-based ISR provides seamless situational awareness. In the air, the most demanding missions are carried out by 6th generation optionally-piloted aircraft, while the fleet of ageing F35 fighters has become a battle management platform as the pilot of each aircraft orchestrates the operations of swarms of autonomous craft.[20] Without the cognitive capacity to manage their movements directly, the pilot simply selects the tactical function to be performed by their associated collaborative combat aircraft (CCA) from an AI-generated list or relies on a default setting based on the situation. Engagements beyond visual range remain the

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[20] Sixth generation aircraft can be defined as extremely low observable airframes with advanced artificial intelligence, computer networking and data fusion capabilities (Lamothe 2022).

providence of high-speed missiles, but smaller autonomous platforms that avoid detection are expected to engage an adversary's autonomous systems in air combat or «dogfighting», using smaller lightweight missiles or pod-based laser weapons that provide a rapid engagement option with deep magazines.

At sea, the autonomous transition has once again given the US Navy a high ship count after years of decline. In addition to the Ford class aircraft carriers already deployed, the shipbuilding plan was altered in the mid-2030s to accommodate construction of six smaller carriers with a mix of manned and unmanned platforms. Lessons from the littoral combat ship (LCS) debacle several decades earlier demonstrated the importance of good conceptual planning and solid engineering, particularly aboard a vessel that might not have the same level of continuous maintenance as manned platforms. A fleet of smaller autonomous vessels, operating in conjunction with these carriers, provides addition firepower and protection. These autonomous systems follow a similar operational concept as UGVs or UAVs. With autonomous refueling and robust communication and data sharing networks, midsized UAVS have both endurance and numerical superiority compared with most other states' air force. In space, a broad network of satellites provide communication and sensor coverage, while NASAs cooperative partnerships with private actors enabled the completion of a new orbital space station as well as a logistical base on the lunar surface that has a tension-filled existence with the Chinese base as its closest «neighbor».

In sum, the United States retains a high-tech military with a global footprint, although larger portions of the globe – and particularly outer space – are now more contested than in previous decades. Considerable effort is expended to protect defense and intelligence related assets in space, as well as the substantial private commercial interests with which the US military has cooperative relationships. The proposed doctrinal evolution toward networked algorithmic warfare can provide an advantageous (albeit high-risk) means of leveraging the advantages offered by AI, autonomy and the next generation of battlefield connectivity.

4.3.4 Future force structures summary

A number of preliminary conclusions can be drawn from the preceding vignettes that outline possible future force structures. Many states are likely to have similar systems in their force structures. For example, many will deploy a mix of autonomous and manned platforms, bound together by some sort of communication network in order to leverage the advantages of autonomy. National characteristics, geostrategic considerations, strategic cultures, and the comparative strengths of domestic research and innovation ecosystems will influence which domains are prioritized and the level of autonomy granted to robotic systems. These systems are likely to have significant qualitative differences, particularly regarding energy storage, network architectures, and software algorithms. As software becomes an increasingly decisive element in the overall performance of military systems, national proprietary considerations will likely prevail over the potential income generated by weapon exports and states may not have the same access to military technology.

It is also important to remember that technology will have significant effects on other important warfighting functions not discussed in this report. Supporting functions such as information processing and analysis, command and control, protection, and sustainment will benefit from many of the most relevant emerging technologies over the next 30 years. Furthermore, technological changes in society will influence the ways in which warfare is conducted, which in turn will influence future force structures. For example, the ability to conduct non-kinetic cyberattacks such as the well-known 2009 Stuxnet operation against Iranian enrichment facilities was possible due to the growing digitalization of industrial equipment. Similarly, information and persuasion operations via social media represent an old idea that has been reinvented for the internet age, with a far greater reach than was possible only a few decades ago.

The world's military forces are not isolated from the society to which they belong. They are therefore impacted by the technological innovation that occurs outside the defense sector, but deployed military systems do not necessarily reflect the most cutting edge technologies available. While a 19 year old from 1992 might be awestruck by the military technology of 2022, today's teenager is likely to view the military as severely outdated. The military in 2050 will likely have a similar pattern: approaching science fiction by today's standards but somewhat outdated by the civilian standards of the day.

The technologies and military systems discussed above are not necessarily discontinuous in nature, but have the potential to have a discontinuous effect. Likewise, discontinuous technologies need not lead to a disruptive effect on the battlefield but are simply a prerequisite, along with innovative thinking with regard to doctrine and organization. How states choose to shape, organize and deploy their forces can have disruptive effects, even if it entails new methods for employing existing systems. Technology is simply one piece of an extraordinarily complex puzzle.

5 Implications and recommendations

The future does not magically appear – it evolves and emerges from the present. Innovative breakthroughs can occur in both engineering and doctrine, but most of tomorrow's most relevant military technologies are already in existence today. The unknowns are largely related to the speed of technological innovation, the feasibility and performance criteria of potential new military systems, and the extent to which states will acquire and integrate them into their force structures.[21] Analysts have already imagined many potential applications of emerging technologies, although certainly not all of them.

Based on the range of likely military uses for the emerging and potentially discontinuous or disruptive technologies discussed in this report, a number of the potential consequences resulting from the adoption of these new technologies can have significant effects on how states structure their military forces and make decisions regarding the acquisition of new systems. These consequences poses a series of dilemmas for Norwegian decision makers, as well as a number of potential actions to mitigate future risk.

5.1 Implications of emerging technology

Potentially disruptive technologies may have the greatest overall effect on military operations, but it is first worth reflecting over the broad and significant wave of technological change likely to alter warfare in incremental yet significant ways. The digitalization of many aspects of society seems poised to continue, including financial transactions, manufacturing, public services and bureaucratic procedures, educational services, digital assistants, digital cameras and other household environmental monitoring, the broad range of entertainment options, and online social interaction. Just as influence operations and wartime propaganda can spread more easily in an age of globalized social media, societal use of technology will continue to interact with militarily relevant activities in subtle yet significant ways.

The interaction and synergy effects of concurrent developments within multiple technologies and multiple applications also create convergence effects that are both unpredictable and potentially disruptive in nature (Andås 2020, 57–59). Continued advances in battery technology may enable the rapid development of more capable UAVs that are currently hindered by limited energy storage, just as machine learning might further unlock the mysteries of genetics and abruptly open a wealth of new possibilities. The potential for convergence tendencies among these emerging technologies is substantial and can lead to rapid and significant changes even though the technological advances within each field are incremental in nature.

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[21] The context in which military operations occur – a combination of geopolitical, demographic, sociological, and environmental factors that, when combined with the themes in this report, make up the operating environment – will almost certainly influence various aspects relating to the use of new military systems and will be analyzed in a forthcoming report.

Incremental change – often leveraging emerging technologies – will nevertheless have the most visible impact on future military force structures and operations. Battlefield mobility will undergo incremental changes as new lighter materials improve protective gear worn by personnel as well as armored vehicles, increasing range and performance. New chemical compounds, perhaps discovered with the help of artificial intelligence, may increase the speed and range of missile and rocket motors. New techniques related to position, navigation, and timing – including quantum technologies – may enable better navigation in demanding situations such as underwater, underground, or GNSS-denied environments. Production of spare parts using additive manufacturing techniques in the field will lessen – although clearly not end – reliance on supply lines, making military units more flexible and mobile. Biotechnology will improve the robustness of personnel and enhance their human performance parameters. Small sensors and AI together will monitor everything from soldiers in the field to the status of ships engines and predict the maintenance needs of larger platforms or signal when individuals need sleep or medical attention. Sensors will be ubiquitous – both in society in general as well as on the battlefield, and particularly when those two spheres coincide. As the number of sensors increases, so too will efforts to elude or deceive them.

Managing signatures has long been a priority and will become even more relevant in the years to come. Steady and incremental improvements to communications technology push increasing amounts of data further towards the "edge" and the individual, while coordination between humans and machines will require communication links as well. As large numbers of satellites monitor the earth and the heavens, those data links will become increasingly relevant and susceptible to intercept or disruption. This contest playing out in the electromagnetic spectrum may be one of the more decisive of the 21st century. Incremental improvements to effectors will lead to even greater precision, range, and explosive force. Just as cyber weapons offered new capabilities for state and non-state actors, new military applications such as intelligent machine or space-based sensor constellations will lead to the development of new types of effectors designed to disrupt or destroy them. In sum, three decades of incremental change will lead to substantial changes in military operations.

Among the potentially disruptive technologies identified in this report, the issues associated with their use in military systems are significant and yet challenging to predict. Autonomy is one prominent example. In the US, Russia, and China, autonomous systems figure largely in the doctrinal concepts under development in all three states. It is hardly novel to claim that autonomy will have a significant effect on future military operations, but it is worth reflecting over the operational implications of having significant numbers of intelligent machines operating without direct human control. Unmanned systems may require greater numbers of personnel than expected. Although somewhat counterintuitive, recent experience with remotely piloted or minimally crewed platforms, including the MQ-1 Predator UAV (increased intelligence processing needs) and the troubled US Navy Littoral Combat Ship program (onboard maintenance needs suffered with reduced crew size), suggest that removing personnel from the platform can be quite labor-intensive and less sustainable over time (Panter and Falcone 2021, 2022; Thompson 2012).

Other logistical needs – effecting field repairs to UGVs or charging batteries for smaller autonomous drones, for example – may prove to be more challenging and undermine the ambitious doctrines that espouse the use of large numbers of autonomous swarms on the battlefield. The extent to which state militaries successfully utilize autonomous systems may depend on how well these logistical and operational needs are addressed. The specifics of human-machine teaming will likely be critical to an optimal use of autonomous systems. Issues of human trust in machine intelligence, ranging from collaborations between soldiers and robotic ground systems to military commanders' use of AI for evaluating potential courses of action, will determine the safety and efficacy of these systems. The implications of this for personnel selection, training and continuing professional military education can be profound.[22]

Autonomous systems have a range of useful military applications ranging from computer network monitoring, ISR platforms that patrol large geographical areas for irregular or threatening actors, or defensive systems that protect large surface vessels or land-based infrastructure. Many of these systems are already in use around the world, straddling the boundary between automated and autonomous systems. Future systems will be more capable of operating independently. Given a particular mission, the system will be able to carry out its tasks independent of any human intervention, monitoring its surroundings and making decisions that provide the greatest chance of successfully completing its mission while following the rules of armed conflict. Rather than a defensive system that reacts in a pre-programmed manner to an attack, autonomous platforms will likely have the ability to choose whether and which targets to engage. For many, this raises ethical questions regarding the appropriateness of allowing machines to take human life even though certain automated systems currently in use such as the PAC-3 missile defense system or the ship-based Aegis combat system are already capable of similar evaluations. Some actors will press these boundaries even further due to the obvious force multiplier benefits involved, presenting hesitant decisionmakers with the choice of following suit or risking a potential disadvantage due to this ethical asymmetry.

5.2 Implications for force structure design

Many of the other potentially disruptive technologies have a similar set of issues with which military organizations will need to contend, as well as an unknown number of issues that have yet to be identified. These unknowns are simply part of what defines disruption and the deep uncertainty of foresight analysis. The combination of plausible implications arising from the most likely future applications – autonomous systems, human enhancement through genetic editing, directed energy weapons – are challenging enough. There are uncertainties not only regarding the exact specifications of these military systems, but a range of other systems yet to be conceived. This presents any number of dilemmas for decisionmakers tasked with defense policy planning. The possible military consequences of these new technologies must be weighed against the uncertainty regarding their efficacy, the economic costs of investing in new systems and the strategic costs of not investing, and the implications for each state's force structure design. Some

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[22] A recent Norwegian language report is relevant here (Fauske and Strand 2022).

of these dilemmas are described below. Although presented as dichotomies, the solutions to the pairings listed here will be found somewhere on the sliding scale between the two extremities.

Old vs new: A persistent dilemma for military planners is the balance between investments in new equipment and refurbishing or modernizing existing equipment. The projections of future American, Russian, and Chinese force structures outlined in chapter four offers a relevant illustration of this dilemma. Each country has a different combination of systems with varying proportions of newer platforms and outdated ones. Investing in completely new equipment is likely to be cost prohibitive for even the wealthiest countries and replacing familiar systems with new ones introduces other risk factors and integration costs. For some systems – fighter aircraft or submarines, for example – older models are simply not survivable on the modern battlefield without possible additional modifications provided by emerging technologies. On the other hand, re-conceptualizing the role of older force structure elements with the acquisition of new elements could extend their service life. Of course, some smaller systems utilizing new technology – things such as ship-based additive manufacturing, new types of sensors, or exoskeletons for the infantry – can be deployed alongside existing platforms without an excessive number of integration issues. The continued utility of legacy systems – and their ability to operate alongside newer equipment – may become an important factor in a future conflict. As the Russo-Ukrainian war has demonstrated, the loss of modern tier one systems in combat has forced both countries to employ a combination of older and newer systems.

Large vs small: The dilemma of continuing to invest in existing systems versus financing the acquisition of newer capabilities is particularly relevant in an era when relatively inexpensive missile systems are increasingly place larger platforms at risk, and autonomous systems are emerging as a feasible alternative to some manned systems. Some analysts point to recent conflicts such as Nagorno-Karabakh (2020) and the Russian invasion of Ukraine (2022) as indicative of the vulnerability of larger platforms such as main battle tanks or warships (Ackerman 2022; Brimelow 2020; O'Brian 2022). Others offer a more nuanced picture of how such platforms have performed in combat and the lack of logical alternatives to these systems (Lee 2022; Parakilas 2020). Most militaries field significant numbers of larger land-, air-, and sea-based platforms that have been central elements to modern warfare doctrines for at least a century. They are rooted in hard-won lessons from previous conflicts and feature prominently in deeply ingrained operational concepts.

Predicting the end of larger platforms is hardly new. Active debates have raged for decades over the future of the aircraft carrier in the face of anti-ship missiles or the viability of the tank when faced with Javelins or unmanned aerial systems. Those favoring the continuation of a platform-based military see few viable alternatives. As one Australian general noted in 2019, «Tanks are like dinner jackets. You don't need them very often, but when you do, nothing else will do» (Parakilas 2020). Most analysts seem to agree, however, that larger platforms will need greater protection from smaller, cheaper systems if they are to remain one of the pillars of state force structures. To avoid financially burdensome defensive measures, any protective system must therefore have an advantageous cost-exchange ratio – a challenging yet not impossible goal given technological advances in new materials, manufacturing, and directed energy/electromagnetic manipulation.

Critical mass vs. hedging: The US, Russia, and China are developing autonomous or optionally-manned systems that will operate alongside crewed platforms. Even with lower unit costs, autonomous systems entails a substantial financial investment that requires either increased defense budgets or reductions in other acquisition programs. Another challenge will be the re-organization of the force and rethinking operational concepts to best utilize autonomous systems. For small and medium sized states with limited numbers of force structure elements and lower defense budgets, any potential shift to adapt to these new circumstances will necessitate reductions to already limited numbers of ships, aircraft, or armored vehicles. Some analysts view this approach as a strategically advantageous response to conventionally superior adversary (Hammes 2019).

A complete force structure redesign, taking advantage of a networked solution comprising long-range missiles, autonomous platforms, and pre-placed IEDs for NATO allies bordering Russia, may be too radical and risky a shift. An alternate approach might be to adopt a «hedging» strategy whereby a state retains the bulk of its current and planned arsenal, but makes limited investments in smaller and/or autonomous systems to gain experience and thereby be prepared for the high-tech future many analysts have envisioned. One of the risks with such a strategy is that it reduces the already low number of platforms even further to accommodate new types of systems, perhaps to a quantity that is operationally insignificant. Despite the expected cost savings of new materials and manufacturing techniques, continuous reductions in the cost of processing power, and the scalable nature of AI, it will still be expensive to invest in significant numbers of autonomous systems. If potential adversaries are also making similar investments, an arms race dynamic may ensue until some sort of parity is reached. Managing the quality-versus-quantity balance in defense planning will be difficult if emerging technologies mature as many anticipate. This will be even more challenging proposition for smaller states.

Consolidated vs. distributed: A related issue for planners contemplating new force structure designs is a communication network capable of accommodating and coordinating the increased number of sensors, long range fires, autonomous systems, and integration of AI in the decisionmaking process. Much of the benefit of these systems lies in the distributed nature of the system that separates the sensor, effector, and human decisionmaker. The doctrinal concepts discussed by the US, China and Russia suggest that distribution combined with network integration will offer tactical and operational advantages. Even if states resist the transition to autonomy, robotics and AI, the effects of increased lethality from larger numbers of smaller systems may require an even greater dispersion of land forces to reduce the threat posed by the combination of aerial sensors and long-range fires. This will necessitate robust networks for tactical communication. The current tactical data link used by the United States and many of its allies, Link 16, has undergone a number of upgrades during its four decades of service, but its ability handle the volume of data needed to realize a fully networked battlefield is unclear. Other alternatives may be required, such as proposals involving 5G networks and future iterations of wireless technology (Demarest 2022; Trevithick 2022).

Human vs. machine: One logical effect of larger numbers of autonomous systems – whether platforms or individual weapons – is the need for algorithmic coordination due to the cognitive limitations of the human brain. Attempting to retain a human in the decisionmaking loop may be nearly impossible during an engagement involving potentially dozens of platforms and hundreds of missiles converging on multiple targets along with the need to make micro-decisions based on continuously updated targeting information, battle damage assessments, and a myriad of other factors. War will likely remain a human endeavor, but the role of human decisionmaking seems poised to cede a certain portion of the tactical «command» to machine intelligence. As mentioned above, algorithms already control certain defensive platforms and individual missiles. Machine coordination of groups of platforms and weapons simply represents a necessary and logical evolution if the benefits of having greater numbers of autonomous systems are to be fully realized.

Domestic vs. import: Intellectual property rights, proprietary ownership, and the composition of sensitive military systems have been a constant challenge for military exports, even among allies. One recent high-profile example was the refusal of the United States to sell its fifth generation F-35 fighter to fellow NATO ally Turkey after Ankara decided to acquire the S-400 air defense system, based on worries that sensitive details about the aircraft would be revealed to Russia (Mehta 2019). These issues may become even more prominent over the coming decades as software increasingly represents much of the decisive edge in sensors and autonomous platforms. Given the greater ease with which algorithms might be spread compared with bulky hardware, the potential risks of losing military advantage by selling nationally developed AI to other states may prevent exports of certain autonomous systems. States that lack the resources to invest in domestic technology may find themselves at a disadvantage. For NATO members, this may introduce new interoperability issues. How will autonomous systems with dissimilar operating systems train and operate together, particularly if each nation has unique human-machine teaming solutions? More fundamental issues might arise within the alliance as states harboring objections to the use of autonomy on the battlefield operate alongside those employing autonomous systems.

As private commercial entities continue to develop significant enabling technologies – machine intelligence for commercial use, space launch capabilities, or large volumes of data useful for training AI – the role of these actors may shift in important ways. Private actors are often engaged to actively support military operations, from shipping companies providing logistical assistance to private military contractors on the battlefield. Other non-state actors choose to inject themselves into a conflict, including individuals such as Elon Musk offering the use of his satellite internet company Starlink to Ukraine or groups conducting cyberattacks such as the hacker syndicate Anonymous. Still others entities, such as the owners of social media platforms, offer services that are valuable for participants in a conflict even if they do not take an active decision to do so. An implication of a digital, software-based future is the potential for actors possessing valuable resources – whether it be satellite access or reams of training data – to gain greater influence and power in military affairs.

5.3 Recommendations

For the Norwegian Armed Forces, these six dilemmas have already become highly relevant to future force structure planning. If the force structures of Russia, China, and the US were to evolve in the general direction outlined in chapter four, Norwegian decision makers would likely face a number of additional issues. By the mid-21st century, the view may look quite different given advances in military technology and subsequent force structure adaptations. For Norway, the implications and recommendations stemming from these potential developments can be divided into three categories: emerging threats to be addressed through evolving threats and missions, interoperability issues with allies, and choices regarding acquisitions and force structure design.

5.3.1 Evolving threats and missions

Looking once again to the vignettes just presented, autonomous systems linked together by robust network of terrestrial, aerial and space-based nodes are in all domains. Artificial intelligence has advanced to the point where autonomy has become a prominent feature of operational decisionmaking processes. Competition in space and cyber domains is particularly intense. Doctrines centered on human-machine teaming and data integration are viewed as crucial to effective force employment. These and other advances will influence the types of threats that appear on the battlefield as well as present new opportunities for military organizations. Just as the evolution of the Internet led to the emergence of a new warfighting domain, new arenas of competition and conflict may emerge over the next three decades.

Given the potential futures outlined in this report, the Norwegian Armed Forces should:

- *Strengthen its capabilities in the cyber domain* to safeguard the growing role of digital infrastructure in military operations, including the development of appropriate tools and techniques as well as the recruitment of qualified personnel

- *Ensure the security and robustness of communications* by developing a strong digital backbone combined with wireless (5G/xG) networks that ensure a low probability of intercept or disruption such that all force structure elements are able to safely and effectively share data.

- *Invest in space-based infrastructure* to maintain adequate operational capability in the Arctic region and elsewhere, anticipating the additional need for sufficient space situational awareness as LEO becomes increasingly crowded.

5.3.2 Interoperability

As a small European state, Norway contributes to and relies upon the NATO alliance for its security. Pressured to maintain technological parity with China, the United States will continue to develop potentially disruptive military technologies. A perpetual challenge for European allies with more limited defense budgets has always been ensuring the compatibility of their force structure elements with the alliance's largest and most capable member. However, the shift from exquisite systems to a distributed architecture will created new challenges. Rather than simply enabling sufficient communication and coordination between the platforms and personnel from each member state via a joint datalink, the network itself will become the primary capability. Interoperability requirements are likely to become even more stringent as coordination between national assets are replaced with a much greater degree of integration into the network. A key attribute of a networked fight is responsiveness, as the pace of warfighting increases with the introduction of machine intelligence in the decisionmaking loop. To maintain adequate interoperability with the United States and other allies, the Norwegian Armed Forces should:

- *Continue to develop a set of standards* with NATO allies for data exchange, software compatibility, guidelines regarding artificial intelligence, and other aspects of the technology comprising the digital foundation for future joint operations.

- *Develop operational concepts* and best practices for human-machine teaming, recognizing that autonomous systems will be a significant factor on the battlefield means that conceptual preparation can make forces ready to operate effectively as soon as systems are mature and viable.

- *Encourage public discussions about technology ethics*, the likely future of warfare, and the choices facing the Norwegian Armed Forces so that political guidance about themes such as autonomous weapons systems and militarized biotechnology (either use by Norway or by allies on Norwegian territory) can be drafted.

5.3.3 Acquisition and force structure

Norwegian decisionmakers are faced with choices regarding the shape, size, and organization of its future force based the most likely trend trajectories. In an often-cited report from 2011, the American defense official and analyst Richard Danzig cast a critical gaze on prediction in national security affairs. He concluded that the Cold War period was unusually predictable and tempted decisionmakers into making long-term plans that no longer are feasible but nevertheless tempted them to «drive beyond their headlights» in defense-related issues. Danzig argued that a better approach was to enhance foresight efforts to avoid strategic surprise while at the same time preparing for an uncertain future: «people must simultaneously predict and plan for predictive failure» (Danzig 2011). Some of these insights remain highly relevant for the Norwegian Armed Forces.

- *Accelerate some decisions while delaying others*. A robust tactical/operational communications network and a low-cost active protection system for larger platforms are examples of logical rapid acquisition decisions, while others (particularly given the anticipated state of the Russian military over the next decade) might justifiably be delayed so that relevant technologies continue to mature.

- *Prioritize adaptable equipment* by placing a premium on operational flexibility when defining new system requirements, as many military systems are built with the intention of a decades-long long service life but utilize highly complex and specialized components that effectively locks the military into using outdated equipment.

- *Prepare for tomorrow's military* by combining investments in the digital infrastructure for integrating autonomous systems and manned platform with the development of new concepts leveraging these technologies such that the Armed Forces are prepared to integrate new force structure elements as soon as the technology matures.

- *Ensure proper data storage and utilization* in anticipation of breakthroughs in emerging and disruptive technology. Data should be viewed as a strategic asset and a key enabler for the future data-driven battlefield.

6 Conclusions and future research

The primary motivation for conducting strategic foresight analysis is not to offer predictions, but to examine the possible range of future outcomes so that decisionmakers are able to make more informed choices about defense-related topics. Technological change have always influenced military operations and represents a significant – if not decisive – factor in the outcome of military conflicts. State actors such as the US, Russia, and China are focused on developing militarily useful systems from a similar set of emerging technologies such as artificial intelligence, autonomy, brain-computer interfaces, quantum technologies, and robust wireless networks. Doctrinal developments in each of these countries seeks to leverage those technologies in operational concepts that favor AI-assisted data analysis, human-machine teaming, and a high operational tempo. Many of the primary warfighting functions will experience incremental changes and improvements over the next several decades due to advances in technology. If developed as anticipated, the combination of these particular emerging technologies together with new operational concepts may have dramatic implications for the conduct of warfare by the mid-21st century, with potentially disruptive effects on military operations.

The promise of a network-centric and distributed warfighting concept enabled by advanced technologies has tempted military analysts for decades. One central question now being raised by a number of analysts is whether the technology has finally caught up with three decades of hype. In other words, is that promised future actually starting to materialize? Clearly, the answer to this question remains unknowable, as predicting the timing of technological breakthroughs is notoriously difficult. With continuous advances in artificial intelligence and repeated examples of the susceptibility of larger platforms to small and cheaper precision weaponry, the future composition of state force structures is increasingly difficult to discern. Larger actors such as China and the United States are investing heavily in autonomous systems and other emerging technologies while retaining sizeable numbers of force structure elements in need of modernization. Due to their size and budgetary largess, these states are able to diversify and prepare for the future they are actively attempting to bring about.

These developments present both challenges and opportunities for the Norwegian Armed Forces. Although they lack the structural breadth and financial wherewithal of the larger actors discussed in this report, a few realistic measures to leverage the potential opportunities and minimize the risks should be economically feasible. Investment in expanding and securing digital infrastructure is a necessary step regardless of the exact force structure elements that ultimately are included. Conceptual and technical work to ensure interoperability with NATO allies is another realistic and crucial measure for effective operations in the future. Finally, current and future acquisition projects should emphasize adaptability and «future proofing». Even if the future does not evolve in the manner described in this report, adaptability and flexibility will be useful for the future that does ultimately emerge.

There is still much more work to be done. As the vignettes indicate, a host of other relevant factors will influence the overall context in which military forces are employed – what is often referred to as the future operating environment (FOE).[23] Understanding the types of military equipment that might be found on the future battlefield is useful, but additional details are needed to envision all the relevant aspects of potential military operations of 2050. As it does today, the global strategic landscape acts as an outermost layer of the FOE, shaping it through geopolitical developments, demographic trends, economic dynamics, changes to the climate, and shifting societal patterns. These and other factors will influence which underlying tensions (such as great power rivalries or resource scarcity) might spark military confrontation, the regions (the Arctic or the South China Sea, for example) and landscapes (megacities, deserts, space or cyberspace) where those conflicts will occur, and which types of actors (perhaps even a mix of states, insurgencies, private military companies and major corporations) may be involved. It is only within this wider context that force structure analyses first become relevant. The strategic landscape addresses some basic questions about the future of armed conflict (*why, where, and who*), whereas force structure analyses such as the one contained in this report and its predecessor are an attempt to understand what these actors will fight with in future conflicts.[24]

After analyzing the strategic landscape and using the notional future force structures from this report as inputs, we can begin to assemble the puzzle pieces into a comprehensive whole that assists our understanding of how future conflicts might be fought and thus better glimpse the possible future character of warfare. At the very least, it is worth contemplating what those changes can entail for future force structures and acquisition policies. More broadly, it will be important to set these and other findings into the wider context of the future operating environment to prepare the Norwegian Armed Forces for the military operations it will be called upon to conduct over the next decades. Our view of the future may be obscured, but a nearsighted focus on the present will almost certainly lead to unpreparedness in the years to come.

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[23] Another term for this concept often used within the NATO alliance is the future security environment (FSE).

[24] Existing research efforts at the Norwegian Defence Research Establishment (FFI) will be crucial to this effort, including projects on global trends, military technology, societal security, and many other relevant themes. A previous report analyzed the potential effects of EDTs on the capabilities of violent non-state actors. See Mayer et al. (2021).

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About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's mission

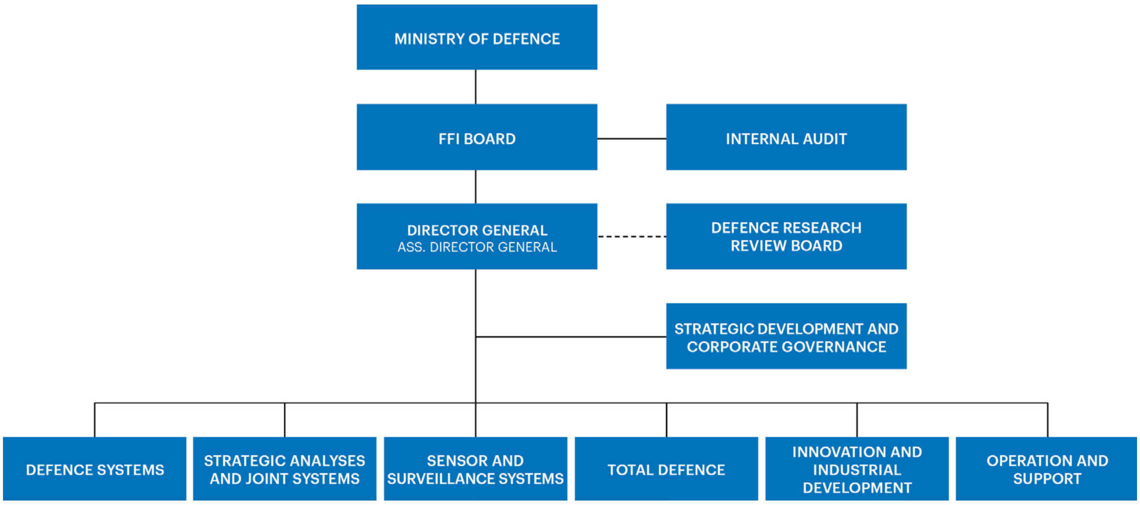
FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's vision

FFI turns knowledge and ideas into an efficient defence.

FFI's characteristics

Creative, daring, broad-minded and responsible.



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