Issue Brief

China's Military AI Roadblocks

PRC Perspectives on Technological Challenges to Intelligentized Warfare

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Executive Summary

China has made significant investments, and apparent progress, in military AI over the past several years. Given AI and related emerging technologies could play critical roles in future wars, the U.S. national security establishment is worried about falling behind China in developing and deploying these technologies.[1] Such concerns have elicited much attention and alarm in the United States.

It is difficult, however, to develop a comprehensive understanding of where each military stands when it comes to military AI development and adoption, let alone conduct a direct comparison between the two. Moreover, often missing from existing assessments of Chinese military AI are Chinese perspectives on their own progress, or lack thereof, in developing and fielding AI-related technologies and capabilities. This report seeks to fill that analytical gap.

This paper outlines several of the key challenges Chinese defense experts argue China is facing regarding the development and deployment of AI and related emerging technologies. It draws on 59 Chinese-language journal articles published between 2020 and 2022 by People's Liberation Army (PLA) officers or researchers, engineers in the Chinese defense industry, and academics working on AI and other emerging technologies.

Key findings include the following:

1. In keeping with the findings of previous CSET analyses, Chinese defense scholars believe that AI and other emerging technologies present China with a unique opportunity to catch up to or surpass the United States militarily.

2. Many of them are concerned, however, that the PLA remains behind the U.S. military in developing and fielding AI and related emerging technologies.

3. Chinese defense experts claim that the PLA is facing barriers to developing and deploying AI and related emerging technologies. The obstacles the experts highlight are similar to some of those with which the U.S. military also appears to be contending. For instance, the Chinese observers are concerned about the

PLA's ability to guarantee network and cyber security, maintain communications in future high-intensity conflicts, and develop trustworthy AI systems.

4. The experts also point out issues that may be especially relevant to the PLA's ability to effectively use AI-enabled military systems. These concerns revolve around military data collection, management, and analysis, as well as the development of high-end sensors. They also appear worried about the PLA's insufficiently robust military standards and testing and evaluation practices. These problems, as well as those mentioned in the above paragraph, may complicate China's path toward carrying out AI-enabled systems warfare, a key operational concept that the PLA believes would help it win future wars.

5. Contrary to some U.S. discussions of China's views of military AI, many of the Chinese experts whose arguments have been analyzed in this report voice misgivings about using insufficiently trustworthy AI systems in military contexts.[2] They also express concerns about the risks of outbreaks or escalations of wars, civilian deaths, and friendly force targeting by AI-enabled military systems due to insufficiently trustworthy AI. Finally, they note that untrustworthy military AI systems may be less effective in future wars.

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Introduction

Chinese defense doctrine and writings envision China's military modernization to be unfolding in three successive but often overlapping phases: mechanization (机械化), informatization (信息化), and intelligentization (智能化). When Xi Jinping came to power in 2013, China began to focus on preparing for informatized warfare, or using information technology to improve command and control, aid precision strikes, and utilize space, cyber, and electromagnetic capabilities.[3] In his 2017 speech at the 19th Party Congress, Xi called for the PLA to realize basic mechanization and make progress toward informatization by 2020.[4]

In the same speech, Xi exhorted the PLA to speed the process of military intelligentization, broadly defined as the use of artificial intelligence (AI) and other advanced technologies for defense applications.[5] The Chinese government and strategic community are confident that AI and other emerging technologies could provide the PLA with an opportunity to catch up to, or even surpass, the military power of the United States.[6] For instance, prominent PLA affiliates, such as Lieutenant General Liu Guozhi, formerly of the Central Military Commission, have argued that when it comes to military capabilities, intelligentization is a "rare opportunity" to "overtake [competitors] on the curve."[7] Official government guidance mirrors the leadership's growing focus on intelligentized warfare. China's 2019 Defense White Paper noted the PLA's increasing focus on bolstering its "intelligence" in warfare, while the 14th Five-Year Plan directed the military to "accelerate integrated development of mechanization, informatization, and intelligentization."[8] Indeed, intelligentization has become the lodestar for the PLA's development and modernization.[9] The PLA has not, however, released official guidance on its concepts for intelligentized warfare, nor precisely on how AI and related technologies factor into the concept. Moreover, definitions of the term, as well as that of informatization, remain purposefully vague.

At the same time, Chinese military strategists and defense academics have published thousands of media commentaries, think-tank reports, and journal articles that can help analysts gain a sense of how China is thinking about using AI and related emerging technologies in warfare.[10] The majority of these materials are published in Chinese. While they are generally under-examined by English-speaking experts,

several researchers have analyzed varying selections to glean insights into how Chinese analysts think future wars will be fought. Some reports focus on how Chinese defense experts envision how AI and other emerging technologies will revolutionize military capabilities, while others focus on these technologies' impacts on deterrence and strategic stability.[11] Still other research interrogates military-civil fusion programs, corporate and academic initiatives to boost military intelligentization, and doctrinal debates.[12]

AI and other emerging technologies such as uncrewed systems, autonomy, and data analysis appear central to Chinese military concepts for fighting future wars. There is, however, relatively limited research focused on understanding how Chinese strategists and defense experts view their own country's progress toward developing and deploying these technologies and capabilities, which are ultimately meant to usher in the final stages of China's military modernization. It is this analytical gap that the report seeks to fill.

Through a review of 130 Chinese-language journal articles about AI and the future of warfare, I identify several areas in which Chinese defense experts believe the PLA is facing difficulties in developing military AI and related emerging technologies. The report also provides information on the technologies that Chinese authors believe Beijing should develop to redress its current shortcomings. That the papers are Chinese-language journal articles is significant, as they are meant to contribute to the Chinese academic literature on military AI and other emerging technologies and are aimed at local defense experts. I argue, therefore, that these papers contain insights that are worth noting since they likely reflect aspects of ongoing debates in China over the military relevance of AI and other emerging technologies.

A reading of Chinese journal articles about the military applications of AI and related emerging technologies conveys the sense that China is hopeful about the military utility of AI and is focused on realizing its potential. At the same time, Chinese defense experts are concerned about the trustworthiness of AI systems and worry that Beijing may be trailing the United States in the development and deployment of AI and related emerging technologies in several key areas. Moreover, many of the articles I reviewed reveal doubts about China's ability to develop several technologies that would allow it

to catch up to, or surpass, the U.S. military. While the analysis in this report has a number of limitations, it nonetheless reveals important, and at times unexpected, insights into how Chinese defense experts view their own country's capabilities and progress on military AI and related emerging technologies.

Scope and Methodology

This report is based on an analysis of reflections, hypotheses, and arguments about military AI and related emerging technologies in a corpus of 130 Chinese journal articles authored by PLA-affiliated and non-PLA-affiliated Chinese defense experts. These papers were published between January 1, 2020, and December 31, 2022, and were captured in a China National Knowledge Infrastructure (CNKI) snapshot on March 30, 2023.*

Of these 130 articles, I focus most closely on the 59 papers that featured discussions of perceived barriers to the development and fielding of military AI and related emerging technologies. Twenty of those 59 were authored by affiliates of the PLA or its universities and academies; 16 were by engineers or researchers working at companies or research organizations in the Chinese military industrial complex; 12 were by academics at non-PLA affiliated universities; and the other 11 had no author affiliation information (8), were written by scholars at companies without clear links to the PLA or the Chinese defense industry (2), or were authored by researchers affiliated with Chinese ministries (1). In terms of the journals in which the 59 papers were published, over three-quarters appeared in publications managed by the PLA or its academies/universities, organizations in China's military industrial complex, or other Chinese government entities.[13]

For each of the 59 papers, I created a detailed log documenting concerns the authors outline about the current state of AI and related emerging technologies; authors' views on the difficulties of developing and/or operationalizing AI-enabled military systems; and, where relevant, recommendations that the scholars make for China to enhance its ability to develop and deploy military AI systems and related emerging technologies. Some of the authors note problems all militaries are facing, while others point out

* See Appendix A for a full explanation of the methodology for generating the CNKI snapshot. Because of the paired keyword approach, the snapshot captured articles that were not relevant to military AI. To determine the final list, the author read the titles and abstracts of every article captured in the snapshot and determined whether each was relevant to military AI. This process helped narrow down to a list of 130 articles relevant to military AI, each of which the author read in full.

specific issues with which China is having difficulties. In this paper, I identify whether the concern is China-specific or not.

In some cases, authors did not identify current shortcomings in China's military AI capabilities but provide recommendations for future development. Given the potential professional consequences associated with openly criticizing the PLA and its capabilities, I treated these recommendations, as well as general statements about China's technological deficiencies, as evidence of areas in which Chinese defense experts believe the PLA needs to make progress to become a world-class fighting force.

The 59 papers in the dataset broadly fit into seven categories:

1) Discussions of the current state of AI-enabled military capabilities, many of which include analysis of limitations and recommendations for developing specific technologies;
2) Broad overviews of the expected future capabilities of AI-enabled military systems;
3) Examinations of the impact of AI and other emerging technologies on strategic stability;
4) Surveys of developments in specific military fields during a certain year;
5) Coverage of how different militaries (mostly the United States) have approached developing specific AI-enabled systems;
6) Discussions of the moral, ethical, and legal aspects of using AI-enabled military systems; and
7) Technical papers on specific technologies or capabilities.

The majority of the papers I cite below are from the first category. In some instances, however, I use information from articles in the other categories. Prior to presenting the findings of my research, several caveats are in order.

First, the study analyzes perceived barriers to the Chinese military's adoption of AI and emerging technologies (and their potential use and utility in future war), but it is unclear to what extent these perceptions match reality. Not every author is affiliated

with the PLA, which likely limits their knowledge of and access to information about sensitive military technologies. Even PLA-affiliated authors may not be aware of the latest advancements in the military's development and adoption of AI and other emerging technologies or be authorized to publicly discuss this information. Therefore, this paper does not make any claims about the influence of the cited authors—or their views—within the PLA or broader Chinese defense establishment.

Second, this report avoids linking known Chinese technologies or capabilities with the cited experts' views of extant AI-enabled systems and related emerging technologies; it solely intends to illustrate how Chinese defense experts perceive barriers to the PLA's efforts to develop and deploy these systems, technologies, and capabilities. Because the information relayed in these articles is aimed primarily at other Chinese defense experts, it is unlikely the authors would intentionally misrepresent or mischaracterize certain technologies or capabilities. That said, scholarly research varies in terms of accuracy and reliability, and as such, the overall assessment presented in this paper is only as precise and comprehensive as its source material.

Third, the report features papers available in the CNKI database up to December 31, 2022, which may not sufficiently capture articles in newer or more specialized journals.

Fourth, the report focuses on only a subset of perceived challenges to AI adoption in the PLA, including those related to technology, standards, and testing and evaluation. Many other concerns are also raised in the articles reviewed for this study, including those surrounding operational concepts and workforce issues, but they are not analyzed below.

Finally, as the Chinese political system tightens, it may become more and more difficult for Chinese experts to voice views at odds with official Party standpoints. Self-censorship could impact the content of the articles, while state censorship could remove entire publications, thereby skewing the dataset and the analysis. Given the opacity of both the Chinese government and military, however, these articles may provide insights into Chinese strategic thinking on several technological issues that the PLA may be facing as it continues to modernize.

A Brief Survey of China's Progress Toward AI-Enabled Warfare

Chinese officials believe AI could usher in a new revolution in military affairs (RMA) that could fundamentally alter how future wars are fought.[14] Senior Chinese officials argue the PLA has an opportunity—given China's strong science and technology base—to develop cutting-edge, disruptive AI-enabled military capabilities.[15]

Xi's focus on military modernization has led the PLA to augment its drive to realize scientific and technological advances, or "innovation-driven development."[16] On top of a renewed focus on S&T developments, in 2015 the PLA embarked on significant reforms aimed at driving military modernization and improving the PLA's ability to conduct joint, multi-domain operations.[17] As part of these reforms, the PLA established the Strategic Support Force (SSF) to oversee the development of electronic, psychological, cyber, and space-related military capabilities. The SSF was recently re-organized into the Information Support Force, Cyberspace Force, and Aerospace Force.[18] The Science and Technology Commission, which is tasked with driving science and technology innovation, was formerly under the purview of the General Armament Department but is now a standalone Central Military Commission entity.[19] The PLA has reformed the Academy of Military Science and directed it to combine emerging technologies with novel operational concepts.[20] Additionally, the Chinese military is leaning on a range of defense-related research institutions, as well as defense industry players, to create innovative technologies and concepts for future warfare.[21] In short, China's military reforms and modernization are aimed at helping the PLA develop and field novel technologies, as well as create new operational concepts, in order to become a world-class fighting force by the middle of this century.[22]

Previous research has outlined how the PLA is developing and purchasing a wide range of AI-enabled military systems. For example, CSET research has found that the Chinese military is acquiring AI-enabled technology for intelligence analysis, information warfare, logistics and predictive maintenance, and navigation and target recognition.[23] The PLA is also reportedly developing machine learning for remote sensing and situational awareness; AI-enabled communications technologies that are better protected from jamming; neural networks capable of guiding missiles and hypersonic glide vehicles; unmanned, autonomous air, ground, ocean surface, and

underwater vehicles; and AI-enabled data management and fusion capabilities, among other applications.[24]

Chinese defense academics and strategists have authored myriad publications exploring future operating concepts and detailing how AI and other advanced technologies may impact future military capabilities. Previous analysis has found that Chinese strategic thinkers believe that AI and autonomy will increase the speed and improve the effectiveness of military operations and aid in detection, targeting, and strikes.[25] They see improvements in intelligent munitions, aerial drones, and exploitation of intelligence, surveillance, and reconnaissance (ISR) data as among the most important developments driving advances in warfare. AI will, they argue, enhance battlefield sensing, improve command and control (C2), aid decision-making, and shorten the OODA (observe-orient-decide-act) loop.[26]

Chinese Experts' Views of AI-Enabled Warfare

Many of the journal articles surveyed for this report feature similarly exuberant expectations. The authors generally believe that advancements in algorithms, communications technologies, sensors, and data processing will lead to improved interconnections among weapons, equipment, and soldiers. Advancements in AI, they claim, will also augment targeting and speed China's development of joint, multi-domain warfighting capabilities. They note how the deployment of next-generation command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems will provide militaries with better situational awareness, battlefield reconnaissance, long-range precision strikes, and more efficient damage assessments.[27]

Others argue that next-generation technologies such as 5G will ensure "seamless networking among unmanned systems."[28] Some Chinese commentators contend that unmanned aerial vehicle (UAV) swarms will improve advanced militaries' ability to strike adversaries.[29] And yet others assert that soldiers and intelligent systems will "seamlessly collaborate," allowing for the execution of joint, multi-domain operations.[30] Autonomous machines will, according to some scholars, vastly reduce the number of humans on future battlefields and expand the depth of the battlespace.[31] Finally, the Chinese experts speculate that technological progress will allow for advances in cyber, psychological, and cognitive warfare.[32]

The above is only a small selection of the diverse predictions that Chinese scholars make about the impact of AI and related emerging technologies on future military capabilities. They are representative, however, of the general view that progress in AI will allow advanced militaries to improve their C4ISR, data analysis, and strike capabilities, gradually remove humans from future battlefields, and field increasingly autonomous systems. AI-enabled gathering and processing of information will, they argue, lead to faster and better decision-making and more precise targeting, allowing the PLA to become a leading fighting force. The integration of emerging technologies with cutting-edge military systems will, in the words of one scholar, lead to a "1+1>2" effect, meaning the next-generation kill chain will be greater than the sum of its parts.[33]

Despite their predictions about AI-enabled improvements in warfighting capabilities, many scholars also voice concerns over the potentially destabilizing effects of AI-enabled military systems. The majority of scholars whose writings are referenced in this report believe emerging technologies could negatively affect strategic stability, leading to the increased incidence of preemptive strikes and arms racing dynamics and complicating escalation control.[34] Moreover, they worry about the proliferation of AI-enabled equipment to terrorists and other non-state actors.[35]

As a consequence, the scholars surveyed here repeatedly note that AI is a "double-edged sword," as it provides opportunities for military advancement while concurrently amplifying risks.[36] Despite these concerns, they appear to favor developing next-generation military capabilities, as their successful operationalization would provide the PLA with its best chance at triumphing over adversaries in future combat.

There is, however, a significant gap between predicted future capabilities and extant technological realities. The remainder of this report focuses on the technological barriers Chinese observers identify that may hinder the PLA's modernization efforts, as well as their recommendations for R&D of specific technologies and capabilities that will, they hope, allow China to overcome its current shortcomings.

Technological Barriers to Developing and Fielding Military AI and Related Emerging Technologies

U.S. defense officials and industry leaders are concerned that Beijing could surpass Washington in the development and deployment of AI-enabled military capabilities.[37] The majority of the defense experts whose articles are analyzed in this report, however, believe that the United States appears to be ahead of China regarding the military use of AI. Several papers outline publicly reported U.S. tests of AI-enabled systems and argue the United States continues to outpace China in the development of military AI.

Many Chinese scholars also note China's technological deficiencies. One article in the *National Defense Technology* (国防科技) journal, written by authors from the Laboratory for High Technology (高技术实验室) at Tsinghua University (清华大学)—often referred to as China's Massachusetts Institute of Technology (MIT)—argue that, "compared with other military powers in the world, military intelligence in China is still in its infancy."[38] This is, perhaps, an overstatement of China's relative technological shortcomings. But other scholars also note technical issues with AI and other emerging technologies that hinder their military application both in China and globally. The following sections delve into several perceived technological barriers to the use of AI and other emerging technologies in warfare, including those related to trustworthy AI, data, network and cybersecurity, sensors, communications technologies, standards, and testing and evaluation. In the majority of the following sections, I also discuss the proposed technologies the experts identify that could aid Beijing in overcoming its current deficiencies.

Artificial Intelligence Systems: Capabilities, Characteristics, and Concerns

Chinese defense experts believe emerging technologies will increase the speed of combat, battlefield unpredictability, and the fog of war.[39] While they argue that AI-enabled military systems will play a role in creating these conditions, they also note the need to use AI to counteract these potential battlefield eventualities. The thinkers' predictions about the future of AI-enabled systems and their impact on the battlefield, however, are tempered by a notable lack of trust in the technology as it exists today.

The authors voice doubts about the current capabilities of AI technologies, noting that AI is currently "weak," or best suited to handle specific tasks with clear requirements and boundaries.[40] AI still struggles to understand abstract concepts, autonomously reason, and make decisions.[41] Furthermore, it is unable to reason beyond mathematical calculations, rendering systems that employ AI unable to make value judgments or differentiate between combatants and non-combatants on the battlefield.[42] The narrow applicability of AI-enabled systems limits their utility, as well as the broader development of "intelligent warfare," at least in the short term.[43]

Chinese observers also appear to harbor deep concerns that **explainability** gaps could cause humans not to trust AI-generated decision recommendations.[44] Some authors note that lack of explainability poses hidden dangers for AI's application.[45] Other experts articulate concerns about ensuring systems' **predictability** and, perhaps most importantly, **controllability**, as losing control of AI systems could increase the risk of escalation and broader instability.[46]

The authors also express concerns about trust in AI that should be familiar to those in the U.S. military. There is a concern that the systems are insufficiently **robust** or **secure** to operate effectively, given the uncertainties of contemporary or future battlefields, or to be resilient to shifts in the operational environment.[47] Moreover, an overreliance on such AI systems could lead to inadvertent escalation or automation bias.[48]

Given the "slow and immature development" of AI technology, the experts argue that, as AI-enabled and autonomous military systems become increasingly complicated, they will continue to be **unreliable**, **fragile**, and **unstable**, leading to serious safety risks, increased chances of miscalculation, and uncertain efficacy.[49] Due to the increasing complexity of AI systems, some authors worry that configuration errors will lead to security risks.[50] Other authors lament that AI systems' Achilles' heel is their vulnerability to specialized attacks on their software or hardware.[51] Given AI's reliance on high-quality training data, experts note that neural networks trained on insufficient data struggle to generalize their applications and continue to be vulnerable to disruptions such as adversarial samples, or inputs designed to cause machine learning models to make errors.[52]

The scholars also contend that current AI-enabled military systems are prone to algorithmic bias, which could lead to misjudgments, false alarms, and other erroneous outputs that could threaten strategic stability.[53] Given these challenges, as well as those related to guaranteeing safety, at least one expert explicitly notes the importance of exercising caution in applying military AI.[54]

Table 1: Concerns About the Trustworthiness of Current AI-Enabled Systems

Trustworthy AI Term[55]	Examples of Chinese Commentators' Expressed Concerns
Explainability	1. Explainability is one of the main bottlenecks restricting the development of AI technology.[56] 2. Machine learning-driven AI algorithms have weak explainability.[57] 3. The "black-box problem" of machine learning limits explainability.[58] 4. Autonomous weapons systems depend on fuzzy logic, neural networks, and deep learning, all of which reduce explainability.[59] 5. AI algorithms have poor explainability and pose risks should they be used in nuclear command and control or in early warning systems.[60] 6. The lack of explainability negatively impacts trustworthiness.[61] 7. Explainability challenges create hidden dangers for AI application.[62] 8. Current algorithm explainability is insufficient and, along with trustworthiness, will become the focus of future AI development.[63]
Controllability	1. Deploying military AI requires restrictions, due to concerns about the technology's controllability.[64] 2. Humans may not be able to totally control AI systems, which could endanger society.[65]
Reliability	1. AI still has significant limitations regarding reliability, which could make its implementation in military contexts more difficult.[66] 2. Autonomous weapons systems have reliability issues.[67]

	3. Poor reliability of AI-enabled weapons systems could increase the chance of conflict or war between great powers.[68]
Robustness/ Security	1. AI still has significant limitations in terms of robustness, increasing its vulnerability.[69] 2. Deep neural networks trained on specific datasets are vulnerable to deception through adversarial samples.[70]
Predictability	1. AI still has significant limitations in terms of predictability.[71] 2. Autonomous weapons systems depend on fuzzy logic, neural networks, and deep learning, which reduce predictability.[72] 3. The "black-box problem" of machine learning limits predictability.[73] 4. Lack of predictability will increase the risk of accidents and mistakes.[74]
Bias	1. Bias is a significant concern, especially regarding image recognition algorithms.[75]

Source: Author's analysis of selected literature.

Data

Training Data

The militaries that best exploit data will have distinct advantages in tomorrow's wars.[76] In its AI strategy, the U.S. Department of Defense acknowledges both the importance of data and the existing challenges in leveraging data for warfighting.[77] Chinese scholars raise doubts about the PLA's ability to generate, gather, and manage the data necessary for developing and fielding exquisite AI-enabled military systems. Those concerns center on the state of the military's data resources, the overall lack of military-relevant data, and the difficulty of sharing data across different PLA services, arms, systems, and platforms.

First, several scholars discuss issues related to the Chinese military's management and organization of data resources. For example, one paper by experts from the Dalian Naval Academy (海军大连舰艇学院) explains that some military data is written on paper and seldom digitized.[78] This practice creates inaccuracies and increases the difficulty of circulating the data, causing it to be less useful since other portions of the military cannot use it to train their own systems.[79] Moreover, some experts claim that PLA does a poor job of tracking data assets and making them visible to both organizations in the military and defense suppliers.[80] Such deficiencies may hamper the PLA's ability to make full use of its data resources.

The scholars are also concerned about Beijing's access to data for training AI systems.[81] Given that China has not fought a war in over four decades, they worry Beijing does not possess the requisite combat data on which to train intelligent weapons.[82] Scholars note that some of China's military data comes from exercises that lack the scale and intensity of actual combat, which may lead the system to work differently in combat than it did in its training environment.[83] Moreover, simulations are time-consuming and expensive.[84] Relatedly, some scholars worry that data generated in such training environments will be difficult to use in preparation for actual warfare, as the conditions of future battles will likely be considerably different.[85] The limited training data increases the chances AI models will be poorly generalizable, limiting their effectiveness in diverse situations.[86]

Others argue that because AI-enabled military systems generate substantially less data than civilian technologies, they are more difficult to train.[87] Interestingly, some claim that, due to the complexity of modern combat, the fog of war, and potential adversary deception, it is difficult to credibly label data generated in battle, further complicating the training of AI-enabled systems.[88] Moreover, some Chinese experts warn of the difficulty, if not impossibility, of using data to give AI weapons combat experience or the ability to fully understand the complexities of future battles, calling into question their trustworthiness and perhaps even their utility.[89] Such concerns illustrate the difficulties of fielding AI systems that are effective across a range of complex scenarios.

To address these data-related challenges, Chinese authors advocate employing four main strategies: more deliberately capturing and shepherding data; using data science techniques to enhance or expand on small datasets; utilizing human-machine teaming; and partnering with commercial firms that may have, or could create, useful data.

Chinese scholars recommend accelerating research on and development of innovative technologies and methods that do not rely on large amounts of labeled data, such as through the use of parallel systems to optimize AI algorithms for use in previously unknown environments, a technique used to work around limited data samples.[90] Through such innovations, they argue, the Chinese military can break through existing data limitations.[91] Others call for research into simulating the generation of multi-source data and using data-enhancement technologies to expand limited data sources.[92]

While some Chinese defense experts believe Beijing should invest in enlarging its data resources, others emphasize the need to develop learning algorithms for small samples, including through the Bayesian program learning method and transfer learning, or using extant samples to solve problems in similar fields.[93] Interestingly, they point out the possibility of overcoming limited military data samples by leveraging human knowledge, or combining data with knowledge graphs that machines can comprehend.[94] Outside of simply generating more data or adopting special tools to train on limited samples, some authors call for partnering with commercial firms that specialize in data processing. Such military-civil fusion arrangements can, they contend, reduce the military's data processing costs and improve the quality of training data.[95]

Data Processing/Analysis

Chinese scholars are well aware of the potential of advanced data fusion technologies, which promise enhanced situational awareness, faster decision-making, and more precise strikes. Chinese commentators note the need to develop an "all-weather multi-dimensional situational awareness network to realize real-time, accurate and comprehensive understanding and control of the battlefield situation," which they hope to create in part through improved data processing capabilities.[96]

As with aforementioned technologies, however, Chinese observers describe several technical issues plaguing China's extant data processing or analysis capabilities. Some argue that current ISR and weapons systems generate a huge quantity of heterogeneous data that is difficult to process in real time.[97] As noted above, however, questions surrounding the explainability and reliability of such systems have led to concerns over the current limits of the technology.[98] Other experts point out compute-related shortcomings of China's current data fusion technologies.[99] Finally, some analysts note that it remains difficult for the Chinese military to integrate information from radar, electro-optical, sonar, and other sensors with data fusion capabilities.[100]

Given the importance of accurate and reliable data processing and analysis, Chinese experts offer several recommendations aimed at improving China's capabilities. Some argue that it is imperative that China make advances in cloud computing, big data analysis, and data mining in order to find correlations among the large amount of data generated in advance of and during combat.[101] Several Chinese authors argue in favor of developing technologies to analyze the data produced by military equipment in order to perform fault diagnosis and improve predictive maintenance, while others claim breakthroughs in quantum computing would make possible exquisite data fusion capabilities.[102]

While the vast majority of the articles surveyed in this study were published in advance of the October 7, 2022, U.S. export controls on semiconductors, a few papers note the importance of domestically developing the semiconductor hardware that fuels ever-more capable computers that can sift through troves of data.[103]

Network and Cyber Security

Related to their concerns over security and robustness, many Chinese scholars view extant AI systems as highly vulnerable to cyberattacks and other disruptions. While discussing a 2011 cyberattack on U.S. Predator and Reaper drones at Nevada's Creech Air Force Base, the PLA-affiliated authors of one article in the journal *Foreign Affairs Review* (外交评论) note that even the world's most advanced militaries remain vulnerable to cyber intrusions. They describe the difficulties of protecting against network paralysis, where computer networks, systems, or infrastructure are severely

disrupted or rendered inoperable; preventing algorithm tampering; and avoiding data destruction.[104] Other scholars also warn that adversaries could contaminate AI systems' training data, leading those systems to make errors and potentially become unusable.[105] The more data one has, the more difficult it is to protect, and the greater the chance that adversaries can modify data and tamper with algorithms.[106] Finally, some experts worry that attacks on computer systems can damage information processing and control capabilities, and even allow an adversary to gain control of these systems.[107]

The Chinese defense experts contend that the inability to know whether an adversary has penetrated friendly networks magnifies risks surrounding AI's trustworthiness.[108] Some authors posit that countries' inability to fully protect themselves from cyberattacks, coupled with the speed at which such intrusions occur, could lead to the outbreak and escalation of wars.[109] Some scholars even worry that cyber and autonomous weapons might be used to attack nuclear weapons, their delivery vehicles, command and control systems, or other infrastructure, all of which could threaten strategic stability and cause crises.[110]

Given doubts about the cybersecurity of networks employing AI technologies, many Chinese scholars recommend developing cyber-related technologies and methods to protect against future intrusions. While some experts note the potential importance of cognitive computing and intelligent vulnerability detection technologies to better protect AI systems, others argue that adopting elastic, or resilient, network designs and following a "zero-trust" cybersecurity model can improve cyber defenses.[111] Blockchain, others argue, can prevent data tampering and promote decentralization, and thus protect the system from infiltration even if a single network node is compromised.[112]

Sensors

Chinese scholars note the importance of highly-capable sensors for ISR, particularly for undersea detection and tracking of submarines, as well as for satellite detection of conventional and nuclear weapons.[113] As with some of the previously mentioned

technologies, however, Chinese scholars outline a series of issues with China's extant sensors, as well as challenges in fusing the data from disparate sensors.[114]

For example, an article by the vice chairman of the China Sensors and IoT Industry Alliance (中国传感器与物联网产业联盟) spells out several issues not only with China's domestically developed sensor technology, but also with the country's broader sensor industry. According to the author, China produces a large variety of sensors, but their quality and technical level remain well below those of the most advanced international sensor manufacturers, making it difficult for China to compete in many high-tech fields.[115] Because competitors have long produced high-level sensors, Chinese firms have trouble breaking in and gaining market access.[116]

Other commentators note operational domain-related sensor shortcomings. For example, some authors claim that complex, variable ground environments present significant obstacles for sensors.[117] Some experts note issues with sensing ships at sea, due to environmental factors unique to maritime operations, as well as the difficulty of discriminating between military and civilian ships in crowded areas.[118] Still others note the shortcomings of underwater sensors, which they view as insufficiently capable.[119] Finally, some argue that military equipment still lacks satisfactory battlefield perception capabilities.[120]

Chinese authors couple these concerns with a clear understanding of how emerging technologies can be developed to deceive or evade sensors. They note that Chinese hypersonic missiles are effective in part because they have reduced radar reflection areas, relatively flat trajectories, and minimized infrared signatures that can confound U.S. radars and space-based infrared sensors.[121] They are concerned, however, that their own sensors are vulnerable to similar deceptions, including through the use of electro-optical false targets and camouflage.[122]

Looking ahead, the aforementioned vice chairman of the sensor industry alliance notes that industry is concerned that it will be "impossible" for Chinese sensor companies to obtain cutting-edge technologies and processes from developed countries due to the U.S.-China trade and technology competition.[123] Therefore, he argues, China must create a robust industrial policy aimed at funding companies engaged in developing

semiconductors, ceramics, organic polymer materials, and optical fibers for use in cutting-edge sensors.[124] Perhaps most importantly, he notes the need to improve sensor quality while making them smaller, more reliable, and more energy-efficient.[125] Rather than focusing only on cutting-edge sensors, some scholars claim that proliferating sensors in multiple domains—for example, underwater surveillance systems and satellite remote sensing for submarine detection—can improve situational awareness.[126] They argue, therefore, for using vast quantities of sensors to overcome their quality limitations.

Communications Technologies

Chinese strategic thinkers believe communications networks will play critical roles in future battles, but they appear concerned about their current state of development. The following section details issues with communications technologies, some of which are directly related to AI and some of which are not.

Central to anxieties surrounding extant military communications technology is that it is difficult to establish and maintain links with high bandwidth, low latency, and enough capacity to handle ever-growing information transmission requirements.[127] This is especially worrisome regarding video data, which drones and other sensors are generating in greater quantities.[128] Scholars worry that bandwidth issues will impede the transmission of high quantities of data for real-time analysis and processing.[129] Given their dependence on legacy technology, parts of China's military will continue to rely on expensive and fragile data links for some time.[130] Other Chinese experts point out that the collection and processing of information is largely limited to single platforms, and that it is often "impossible" to transfer information from that machine to data processing centers in real time.[131] Data transmission volume limitations and lags degrade military effectiveness, as they imperil command and control and data processing.

Chinese scholars who have weighed in on this issue appear especially concerned about data links for both UAVs and UUVs (unmanned underwater vehicles). With regard to the former, some authors note how jamming and other electronic warfare methods disrupt links with ground stations and imperil the utility of these systems.[132] UAV

reliance on ground or air relays also poses reliability issues, while satellite communications can suffer from slow speeds and long delays.[133] Other experts note that current communications technologies lack the latency, bandwidth, reliability, and quality of service (QoS) that future semi-autonomous UAVs will require to be fully effective.[134] Furthermore, the network requirements for aerial swarms, which must constantly share data with other swarm nodes, are more complex than the comparatively simple remote-control links that simply transit data from drone to operator and back again.[135]

Sub-sea environments pose significant difficulties in the operation of UUVs. Communications are very limited underwater, making it difficult—if not impossible—to establish long-range data transmission links.[136] Such issues complicate operational and tactical coordination among undersea vehicles and other forces.[137]

While some scholars argue it is necessary to boost autonomy to avoid many of the pitfalls of poor-quality or disrupted communications, others note that China should conduct further research on communications networks to increase their stability, decrease delays, and improve bandwidth.[138] The Chinese experts offer a range of suggestions for future communications-related R&D priorities, ranging from multi-hop transmission for underwater networks to cognitive radio technology to reduce disruptions from electromagnetic interference, as well as the use of blockchain technology to guarantee data transmission in contested environments.[139]

Among the more popular recommendations, however, are the use of Internet of Things (IoT) technology and 5G-enabled communications networks. The former can be used to create more robust combat network systems, while the latter boasts higher bandwidth and transmission rates than traditional communications networks.[140] Such technologies can, some Chinese observers argue, enable drone swarm operations, ensure the efficiency of communications, and reduce costs.[141]

On top of IoT and 5G, several scholars believe that decentralized, dynamic, self-organizing networks will define future communications infrastructures. Ordinary data links have static networks that cannot reorganize in real time, but these next-generation networks are better positioned to support coordinated operations.[142]

Dynamic networks, some Chinese commentators claim, can form temporary links for specific missions on demand.[143] Decentralized networks, on the other hand, can be less vulnerable to disruption and achieve greater flexibility.[144] The ability to quickly adapt to drone attrition or electromagnetic interference, especially for autonomous swarms and coordinated missile formations, will likely prove crucial to maintaining effectiveness in the highly contested battlefield environments of the future.

Standards

Despite China's rapid military modernization, several scholars point out that the PLA has insufficient standards for the development and deployment of key enabling technologies, such as deep learning and data use, collection and management, as well as for the creation and management of broader combat systems that rely on those technologies. As with the preceding section, the following one also covers communications technologies, only some of which are related to AI.

According to RAND Corporation studies, Chinese experts appear to believe that future wars will be won by the force that has superior systems of military systems, and the PLA is now focused on developing synergized military operational systems that, the experts believe, will allow it to triumph over adversarial systems.[145] The authors of the papers reviewed for this report agree that developing such systems is crucial, but they appear concerned that the PLA's insufficiently robust military standards may impede its efforts to create them.

For example, many Chinese defense experts note the importance of various aspects of combat "system construction."[146] Such systems should be interoperable and share core design elements, which would obviate the current trend toward development in "scattered and chaotic conditions."[147] Drawing lessons from the United States, some scholars claim that the U.S. military's struggles with inter-system interoperability have led it to postpone scaling up unmanned capabilities while it focuses on efforts to create inter-system interoperability among existing unmanned systems, as well as among manned and unmanned systems.[148]

The Chinese experts note the importance of hardware and software standardization, modularization, and serialization in order to rapidly integrate and upgrade weapons

systems, as well as to construct a flexible and resilient combat system.[149] Without standardization, modularization, and serialization, combat systems—especially those reliant on software—will likely be rigid and fragile, making them vulnerable in future wars.[150] Others note that systemization, generalization, and modularization will also be critical for AI-enabled hardware such as missiles and unmanned equipment systems.[151]

They note, however, that military standardization remains insufficient. In particular, they contend that both intelligent weapons and equipment are still in the early stages of standardization.[152] As noted above, some commentators point out that China's data collection, use, and management practices lack standards, while others argue that UUVs and USVs (unmanned surface vehicles), as well as intelligent support equipment, are being developed in the absence of robust standards.[153] Given these shortcomings, the experts advocate for a variety of standard-building measures.

Several experts call for the creation of standards for algorithms, data, communications networks, and the testing and evaluation of intelligent weapons to allow for the shared planning, design, construction, and testing of combat systems.[154] Some scholars point out the potential utility of establishing organizations to formulate industry standards.[155] Other analysts claim that research aimed at creating shared technical standards for the development of deep learning and neural networks, as well as for big data, cloud computing, and IoT, would support the creation and maintenance of advanced defense systems that depend on these enabling technologies.[156] Others argue for the formulation of standards, including design specifications and manufacturing process standards, for specific defense applications including missiles, UUVs and USVs, as well as encryption systems.[157] Still others note the importance of creating open architectures, modularity and part interchangeability, testing and evaluation practices, and data transmission integration in order to improve inter-system interoperability.[158]

Testing and Evaluation

The Chinese scholars generally agree that testing and evaluation (T&E) is essential for promoting trust in intelligent systems and establishing their combat effectiveness.[159] They also, however, openly express concerns about China's T&E regime for AI-enabled systems.

Some scholars see numerous issues obstructing China's path toward establishing robust T&E regimes. For example, they note that, due to the complexities and uncertainties of future wars, it is not feasible to test autonomous weapons systems in all possible scenarios, making it impossible to fully evaluate them.[160] They also argue that tests themselves may cause safety issues.[161] Some complain about the high costs associated with performing T&E experiments, while others, as noted above, point out the lack of T&E standards crucial to guiding the systematic development of AI-enabled military systems.[162] Finally, experts point out the difficulties associated with evaluating the intelligence of various AI-enabled systems.[163] Such difficulties lead to lack of trust in systems whose level of intelligence cannot be easily verified or validated.[164]

Since T&E protocols for AI-enabled military systems have only relatively recently become an area of focus, the papers feature more detailed discussions about how to establish or improve these regimes than analysis of extant T&E-related problems. Some authors, for instance, call for the formulation of T&E standards for multiple AI-related applications, such as human-machine teaming, brain-computer interfaces, weapons and equipment systems, UAV swarms, and semiconductors.[165] Others argue that China should develop standard datasets for testing and evaluating AI-enabled missile systems.[166] Still others offer specific recommendations for establishing frameworks for simulation techniques, especially for algorithms and weapons, and for constructing dedicated testing facilities for unmanned equipment, among other uses.[167]

Several scholars also note the importance of extensive T&E practices to build the systems of operational systems the PLA will rely on to fight future wars. As discussed throughout this paper, weapons systems rely on communications networks, sensors, and data processing systems, which, if they are not individually tested, might not be reliable. Therefore, some scholars argue that all parties involved in developing intelligent weapons, from device manufacturers to network suppliers and end users, should put their products through rigorous tests before linking the individual systems together to form systems of systems.[168] Others contend that such tests can support the integration and combat applications of military systems.[169] In short, Chinese scholars acknowledge that T&E is an issue at both the component and system levels. It is not enough to test an individual drone. Rather, that drone must be tested by itself and then as a component of a larger system of drones in a swarm, for example.

Key Findings

It would be unwise to take the Chinese experts' arguments outlined above purely at face value. Many of the authors are not affiliated with the PLA, which likely limits their knowledge of China's cutting-edge military AI and related emerging technology development. That said, even PLA affiliates may not be aware of China's latest military technology breakthroughs. Finally, those that are privy to such sensitive information would be unlikely to discuss it publicly.

It is, however, notable that many experts point out a wide range of concerns with the current state of the technologies that, should they further develop, might allow the PLA to better develop and deploy military AI and related emerging capabilities. These papers, therefore, reveal a subset of the Chinese strategic community's insecurities about the development and fielding of cutting-edge military technologies. Below, I outline several of this report's most notable findings.

First, Chinese defense experts anticipate that AI and other emerging technologies will have a significant impact on future military operations and could provide the PLA with an opportunity to leapfrog the United States.

In line with the findings from previously published analyses of Chinese defense scholars' views on the future of warfare, the articles referenced in this report argue that AI-enabled military systems could revolutionize warfare. AI, Chinese analysts claim, could allow China to develop joint, multi-domain warfighting capabilities that it currently lacks. Moreover, improved C4ISR will allow for more precise strikes, superior situational awareness, and more comprehensive battlefield damage assessments. Technological advances will help humans and machines seamlessly collaborate, while UAV swarms and hypersonic missiles will augment militaries' abilities to strike adversaries.

The Chinese scholars surveyed in this review tend to believe that the PLA has an opportunity to overtake the U.S. military should it quickly and effectively develop and operationalize AI and related emerging technologies and capabilities.

Second, that said, Chinese defense experts are concerned that the PLA is lagging behind the U.S. military in AI and related emerging technology development and deployment.

Whereas U.S. experts increasingly voice concern that China has overtaken the United States in the development and adoption of military applications of AI and related emerging technologies, the articles reviewed in this paper reveal an inverse anxiety across the Pacific; Chinese scholars believe the United States is ahead in the race to develop and field AI-enabled military systems.[170]

Third, Chinese defense experts identify certain challenges in developing and fielding military AI systems, which are similar to those the U.S. military appears to be facing.

The U.S. military's AI development efforts are not the focus of this paper. Moreover, the report does not provide systematic comparisons of U.S. and Chinese experts' views of each country's AI-related challenges. That said, based on publicly available assessments of the U.S. military's AI development and adoption efforts and statements made by U.S. military officials, both countries do seem to be dealing with similar sets of issues related to developing and deploying the AI and related emerging capabilities detailed in this paper.[171] They seem to be facing challenges related to creating trustworthy military AI, as well as to managing and fully exploiting data resources while preserving the integrity of communications and computer networks.

Fourth, the authors also identify challenges that may be especially relevant to China and the PLA regarding the development and adoption of military AI and related emerging technologies.

Specifically, the Chinese observers surveyed in this paper note difficulties collecting, managing, and using military-relevant data to train military AI systems, as well as developing the high-quality sensors experts believe will be needed to fight next-generation wars. Some scholars have also noted concerns about the state of China's communications and cybersecurity systems, and their ability to connect vast arrays of sensors and process the information they generate. These observed shortcomings and obstacles raise important questions about China's progress toward implementing its

systems warfare concept, which is a central aspect of China's theory of victory in future wars.[172]

The authors' views on China's apparent deficiencies related to establishing standards and T&E protocols also merit mention. A lack of military standards complicates the development of interoperable systems, while poor T&E practices create obstacles to trusting AI-enabled systems, determining their efficacy, and training them for future wars in complex environments. According to these papers, the lack of robust standards and T&E resources are some of the most serious threats China faces in creating the systems that would allow it to fight future wars according to its nascent operational concepts.[173]

Fifth, Chinese defense scholars voice concerns about AI risks and the trustworthiness of AI systems.

Chinese scholars' aforementioned concerns about the explainability, robustness, controllability, and overall trustworthiness of AI systems reveal doubts about the current state of the technology. Potentially more significant, however, are the scholars' misgivings about using AI technologies that are not explainable, predictable, or controllable. They explain that such deficiencies could lead to unwanted outbreaks and escalations of wars, as well as to civilian and friendly force targeting by autonomous systems. Moreover, they note that insufficiently trustworthy systems may be less effective for military operations overall, as such shortcomings will inevitably threaten operator trust, making soldiers less likely to use them effectively (or at all).

In short, the majority of experts who discuss the shortcomings of AI systems question whether the technology can be used responsibly and effectively, at least in its current state. Notably, these doubts are largely in line with the Department of Defense's own concerns about using AI systems that are insufficiently trustworthy in operational settings.

Conclusion

This report analyzes 59 papers by Chinese defense experts in order to glean insights into the areas in which China may be facing technology-related barriers to developing and deploying AI and related emerging technologies and capabilities. According to these experts, the PLA still faces significant issues related to trustworthy AI, data management and use, sensor technology, network and cybersecurity, communications networks, standards, and T&E that may hinder the PLA's military modernization in the short to medium term. Moreover, Chinese scholars' concerns about the risks associated with unproven AI technologies reveals that at least some members of the Chinese strategic community may have misgivings about using unproven capabilities in war.

Such perceptions indicate that the United States and China may be well-served by developing and maintaining dialogue channels through which to discuss the risks posed by AI. Though the initial U.S.-China AI discussions held in Geneva in May 2024 revealed bilateral tensions over AI-related issues, they were nonetheless a step in the right direction.[174]

In the current climate, however, it would be difficult to conduct military-focused dialogues on AI that lead to binding agreements. That said, the two sides could conduct bilateral discussions on limiting the role of AI in nuclear command and control, setting standards for testing and evaluating AI-enabled military systems, and creating confidence-building measures.[175] Such exchanges could lead to improved mutual understanding and, perhaps, forestall military AI arms racing dynamics.

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Appendix A

A CNKI snapshot was generated on March 30, 2023. The author aggregated the CNKI papers published between January 1, 2020 and December 31, 2022 with titles or abstracts that contained the following combinations of keywords related to AI, weaponry, and nuclear deterrence:

English Keywords	Chinese Keywords
deterrence + artificial intelligence	威慑 + 人工智能
deterrence + machine learning	威慑 + 机器学习
nuclear weapons + artificial intelligence	威慑 + 人工智能
nuclear weapons + machine learning	威慑 + 机器学习
strategic stability + artificial intelligence	战略稳定 + 人工智能
strategic stability + machine learning	战略稳定 + 机器学习
weapon + artificial intelligence	武器 + 人工智能

Below are counts of the most frequently observed author affiliations and journals among the 59 cited articles.

Counts of Top Author Affiliations		Counts of Articles in Top Journals	
National University of Defense Technology (中国人民解放军国防科学技术大学)	14	National Defense Technology (国防科技)	9
Northwest Institute of Mechanical & Electrical Engineering (西北机电工程研究所)	6	Military Digest (军事文摘)	5
CETC Key Laboratory of Data Link Technology (中国电子科技集团公司数据链技术重点实验室)	5	Defence Science & Technology Industry (国防科技工业)	2
China Academy of Electronics and Information Technology (中国电子科学研究院)	4	Aerodynamic Missile Journal (飞航导弹)	2
Dalian Naval Academy (海军大连舰艇学院)	4	Dual Use Technologies & Products (军民两用技术与产品)	2
Shanghai Mechanical-Electronic Engineering Institute (上海机电工程研究所)	4	Journal of China Academy of Electronics and Information Technology (中国电子科学研究院学报)	2
Xi'an Microelectronics Technology Institute (西安微电子技术研究所)	4	Measurement & Control Technology (测控技术)	2

Source: Author's analysis of selected literature.

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