Australian Army
Research Centre

Understanding How to Scale and Accelerate the Adoption of Robotic and Autonomous Systems into Deployable Capability

Phase 1—Identifying Barriers

Dr Austin Wyatt, Dr Joanne Nicholson,
Dr Marigold Black and Dr Andrew Dowse

Australian Army Occasional Paper No. 20

RAND AUSTRALIA

This research was conducted by RAND,
sponsored by the Australian Army.

Australian Army
Research Centre

Understanding How to Scale and Accelerate the Adoption of Robotic and Autonomous Systems into Deployable Capability

Phase 1—Identifying Barriers

Dr Austin Wyatt, Dr Joanne Nicholson,
Dr Marigold Black and Dr Andrew Dowse

Australian Army Occasional Paper No. 20

Serving our Nation

ISSN (Online) 2653-0406
ISSN (Print) 2653-0414

DOI: https://doi.org/10.61451/267504

All enquiries regarding this publication should be forwarded to the Director of the Australian Army Research Centre (researchcentre.army.gov.au/contact-us)

To learn about the work of the Australian Army Research Centre visit researchcentre.army.gov.au

Cover image: An Australian Army M113AS4 armoured logistics vehicle, fitted with optionally crewed combat vehicle technology, fires its remote weapon station during a human-machine team exercise.

Contents

Introduction

The emergence of increasingly capable robotic and autonomous systems (RAS) has been recognised as having the potential to become a disruptive wave,[1] raising significant challenges as well as opportunities for militaries. Every major military force has now publicly declared an interest in either developing, utilising or banning RAS.[2] Even world leaders, such as Russian President Vladamir Putin, have issued proclamations regarding its potential impact on the future of warfare.[3] Yet, despite these claims, there have been no documented widescale deployments of weapon systems that one could unequivocally declare to be both robotic and functionally autonomous.

Here definitions are important. For the purposes of this analysis, the definition of RAS focuses on systems that are both robotic and functionally autonomous to the exclusion of remote-operated platforms and non-embodied artificial intelligence (AI) systems. 'Autonomy' refers to the capacity of a system to 'execute a task, or tasks, without human input, using interactions of computer programming with the environment'.[4] Thus an 'autonomous system' can be understood as a system that 'whether hardware or software, once activated performs some task or function on its own'.[5] However, 'autonomy' is a relative, rather than binary, characteristic derived from displayed functionality. It is therefore difficult to cleanly differentiate whether a system is truly 'fully' autonomous. As a result, it is common in the literature and in military strategic documents to refer to categories of autonomy along a spectrum. For example, the Australian Army RAS Strategy Autonomy Spectrum incorporates four levels of autonomy: remotely operated (which are often conflated with autonomous systems), automatic (where a human remains in the loop to monitor and potentially intervene), autonomic (where the human supervises or tasks a system, thus remaining in the decision loop), and autonomous (where the human starts the decision loop but the system can then act independently).[6] Having considered these characteristics, as well as the core question it attempts to answer, this paper utilises the term 'robotic and autonomous systems' to refer to those systems that are both robotic and functionally autonomous—that is, those systems that would be classed as 'autonomous' in the Australian Defence Force (ADF) RAS Autonomy Spectrum.

That is not to say that relevant technologies are not proliferating; powerful AI–enabled tools, remote-operated systems, and even task-based autonomy have clearly all been deployed in some fashion by militaries,[7] by law enforcement agencies[8] and by armed non-state groups.[9] The United States (US) Air Force, for example, has acquired and deployed remote-operated platforms at significant scale and sophistication over the past 20 years, representing 8.5 per cent of its total airframes in 2021.[10] Such actors have employed systems that are capable of operating in an autonomous mode supervised by a human in the loop (such as the Super Aegis II),[11] as well as defensive systems that autonomously engage threats but are subject theoretically (because of the speed of engagement)[12] to being overridden by a human (for example, Patriot, Aegis and CIWS).[13] More controversial are the loitering munitions (such as Harpy, Harop and Shahed-136)[14] which are capable of independently selecting and engaging targets based on matching signatures to a pre-established database.[15] Such systems (which would also include certain cruise missiles such as the Brimstone)[16] have been described in the media as lethal autonomous weapons systems,[17] while debate in the legal[18] and scholarly[19] communities is ongoing.

And yet, something is still blocking states as powerful and wealthy as the US and China from accelerating fully autonomous robotic systems from concept and prototype to a deployable and scalable capability. Even in the Russo-Ukrainian war, the largest land campaign in Europe since World War II, deployment of such systems has been limited to remote-operated platforms. This has included deployment of loitering munitions such as Switchblade and Shahed-136. But the utilisation of such platforms is not new and they are, at best, extensions of the operational concepts utilised over two decades ago. In 2001, for example, the US utilised remote-controlled aircraft for direct strikes, and the use of such systems as a 'poor man's air force' was demonstrated by ISIS as early as 2015.[20] Therefore, in the context of the current conflict in Ukraine, the question arises as to why the Russian military has elected to deploy long-retired tank models from storage in order to continue the fight rather than to use its much-vaunted Uran series of uncrewed armed ground vehicles.[21] Why hasn't the uncrewed version of the T-14 Armata tank moved beyond prototype stage?[22] More broadly, why hasn't the scale of conflict in the Ukraine reached the 'demonstration point' for the use of fully autonomous weapons systems?

To answer this question, it is necessary to go beyond the claims that too little has been invested, that the technology is not yet matured, or that militaries have not recognised the potential value of autonomous systems. On the former, consider that the US invested more in AI-related research in 2018 than Indonesia's entire defence budget that year.[23] While exact figures are unavailable, China is estimated to be spending comparable amounts on related research.[24] Claims that the technological barriers are insurmountable also seem weak against the continued proliferation of commercial AI tools. Neither can a serious argument be made that these states are not sufficiently focused on autonomous systems, with China famously designating them as central to the rise of 'intelligentized warfare' and the pride of place they enjoy in the US Third Offset Strategy.[25]

Thus, it is not the lack of scale, scope and resource capacity that is responsible for the failure to adopt an innovation; rather it is the underestimation of the complexities of the system—barriers—into which the innovation is to be adopted. This situation is made more problematic by the fact that experimentation 'on the bleeding edge' requires an acceptance of the risk that many projects will not reach maturity or will not be accepted into service, sometimes for good technical or operational reasons. Achieving this complex balance has been extensively studied in both the civilian and military literature and it remains a challenge for the ADF.

The announcement by the Department of Defence of the Advanced Strategic Capabilities Accelerator (ASCA)[26] and the release of the Defence Strategic Review (DSR)[27] are indicative of a recognition of this challenge among senior civilian and military decision-makers. The centrality of addressing this challenge was made clear by the fact that trusted autonomy is one of ASCA's initial six priority areas.[28] Similarly, that a chapter of the DSR is dedicated to the need for the ADF to generate asymmetric advantage through technology[29] indicates that this is a challenge at the core of Defence thinking and planning moving forward. The pre-eminence of 'AUKUS Pillar Two'[30] in both AI and autonomous systems is demonstrative that both will continue to be capabilities of significance to the future ADF.[31]

Methodology

Reflective of these strategic steps, the core focus of this analysis is to identify and critically evaluate potential barriers to the adoption at scale of RAS. The first section provides an initial list of barriers to adoption at scale drawn from an evaluation of comparable historic case studies. Specifically, the paper presents a series of two military and two commercial adoption cases. In each of these case studies, a disruptive innovation was transitioned from high technology readiness level (TRL) prototype to full scalable capability. These case studies were chosen because they reflect different facets of the problem of adopting emerging technologies while retaining a strong linkage to military RAS. For example, examining uncrewed aerial vehicle (UAV) adoption by the ADF illuminates barriers and lessons learned from a recent attempt by the ADF to adopt an emergent technology. In a similar vein, the case of directed energy weapons (DEWs) in the US military was chosen as an example because it was an analogous attempt to adopt an emergent technology with comparable resource intensity challenges and strong potential international legal barriers. Similarly, the commercial case studies were chosen because they involved similar technologies (robotics and remotely operated aircraft, respectively) in civilian sectors with comparable dynamics (skilled labour shortages and the need to demonstrate value to leaders in the case of construction, and regulatory challenges in the case of conservation). From these case studies, a list of potential factors is generated to help assess why the actors were, or were not, successful in achieving the intended capability outcomes.

This section is followed by a review of barriers identified in the literature as being particularly associated with RAS. The literature related to RAS, particularly autonomous weapons systems, has grown exponentially in recent years. It is a very useful window into the barriers and challenges that are likely to face RAS adopters, particularly early and first movers. On the basis of this analysis, a list of barriers has been generated that can be compared with those identified in the first section's case studies. This provides the basis for a combined list of factors that are likely to affect whether an actor is liable to succeed in adopting RAS.

Having identified this list of likely barriers, the paper moves to the complex question of why no state has been successful in adopting fully autonomous robotic systems at scale. Considering this question presents unique methodological challenges. Traditionally innovation analysis is retrospective, not prospective; focuses on one actor; and emphasises either the barriers to adopting an innovation or the capacity of actors to identify and successfully adopt a given innovation.

Given the challenges involved, a two-stage methodological approach was taken, combining elements of established innovation analysis methodologies in a novel manner. The first stage involved an initial barrier sensitivity analysis to determine where each state was likely to be 'satisfied' that they had met the barrier. This was an important step because it gave an initial indication of the ways in which different states were approaching RAS, a type of technology rather than a particular platform or weapon system that would otherwise allow the normalisation of adoption barriers for cross-state comparison.

The second stage analysed the adoption capacity of each of the chosen case study states. This analysis was undertaken based on five variables derived from adoption capacity theory[32] and organisation theory of military innovation.[33] The first variable was the state's security threat environment, the influence of traditional and non-traditional security threats on its doctrinal and procurement decisions. Second, consideration was given to the state's resource capacity, which includes military expenditure, the sophistication of the state's domestic military-industrial base and foreign arms acquisition capacity. Next was organisational capital capacity, which has three sub-variables: critical task focus, level of investment in experimentation, and organisational age. The fourth variable was the receptiveness of the domestic audience towards RAS, and the final variable was the state's capacity to develop or emulate a specialised operational praxis (the process by which militaries translate capability into effect) for the use of RAS.[34]

Finally, the paper analyses multiple potential adopters simultaneously and explains the differences between each. For example, why have states with less resource capacity succeeded in deploying key precursor systems (remote-operated systems, and systems with some task-based autonomy) when great powers have publicly claimed to have not reached a demonstration point for fully autonomous weapon systems? This example serves to illustrate the complexities in evaluating both the sensitivity to barriers and the adoption capacity in a predictive manner. While time and budget constraints limited the authors' capacity to consider these issues in close detail, nevertheless the analysis demonstrates that different methodologies were applicable, which affords some useful initial insights.

The states chosen for initial analysis in this paper were Australia, the US, China, the Republic of Korea (ROK), the United Kingdom (UK), Israel and Singapore. These states were chosen in consultation with stakeholders from an initial long list that was based on existing engagement with RAS initiatives; strategic importance to the ADF; comparability of size, capacity, interest or ethical approach to the ADF; and availability of open-source data. It is important to note that the inquiry upon which this analysis is based was confined to identifying the key potential barriers to scalable adoption of RAS, in the context of the potential adopter's capacity and goals.[35] This paper is thus limited by time and resource constraints. Follow-on research would allow for the empirical evaluation of barriers and how they could be overcome by the ADF.

Military Case Study One: UAV Acquisition by the ADF

To date, the ADF is among a small number of states that have not acquired armed remote-operated UAVs,[36] although it has invested in the Ghost Bat (envisaged as a supervised autonomous system). Instead, the ADF's operational experience with UAVs has been limited to utilising unarmed variants, largely for tactical intelligence, surveillance and reconnaissance (ISR). The Australian Army has utilised remotely piloted aircraft since the early 2000s, deploying them across a range of operational environments. By the early 2020s, every infantry and cavalry battalion within the Army had a level of organic UAV capability.[37]

Aside from a brief deployment by the Special Air Service Regiment in Timor-Leste in 2000, the first operational deployment of UAVs by the Australian Army was the deployment of four Aerosonde UAVs to Solomon Islands as part of Operation Helpem Fren, the Regional Assistance Mission to Solomon Islands (RAMSI), in July of 2003. These systems were obtained from the Nervana tactical UAV experimentation program of the Defence Science and Technology Organisation (DSTO), now known as the Defence Science and Technology Group (DSTG) and operated by a detachment of 131 Surveillance and Target Acquisition Battery.[38] Australia's initial UAV commitment was highlighted in the first RAMSI capability publicity event, reflecting a desire to leverage the capability's deterrent value simultaneously with the highly visible stationing of HMAS *Manoora* off the coast.[39] Notably, the UAV detachment rotated out of Solomon Islands in March 2004 without replacement. The explanation for this omission remains unclear. One potential reason is that the battery was set up as (and is still run as) a single enabling unit within the Plan Beersheba[40] framework, meaning that it could not provide sufficient personnel or platforms for a second consecutive deployment.[41] Another potential explanation is that Army did not 'own' the platform, and thus was not able to extend its deployment. Instead, the capability was withdrawn by DSTO (who held the lease) because the first rotation fulfilled its purpose as a successful operational experiment.[42] Alternatively, perhaps the strategic need for such capability had significantly diminished from when the UAVs were initially deployed.[43]

Examining the rapid acquisitions of capability in 2005–2006, a time of high operational tempo for the ADF, offers key insights into how scalable adoption of RAS could be achieved. During this 24-month period, the ADF acquired several UAV capabilities at a significantly quicker pace than anticipated by the UAV Roadmap.[44] Driven by operational demands, the ADF purchased six Skylark UAVs directly from the manufacturer in a rapid acquisition program, gaining a deployable capability within 12 months.[45] Even more interesting was the—nearly simultaneous—response to similar demands for an ISR capability at the brigade or joint task force level. Such a capability was planned under the UAV Roadmap but was years from becoming a scalable and deployable capability.[46] In light of operational demands, Defence took the decision to abandon the intended procurement plan in favour of a capability it could deploy in short order. To this end, the ADF looked to the ScanEagle UAV, which was already in service with the US Marine Corps (USMC). From demand to the deployment of the first ScanEagles, this process was completed in less than 12 months, virtually in parallel with the Skylark acquisition.[47]

Similarly, the Royal Australian Air Force (RAAF) leased the Heron UAV as an urgent stopgap, reflecting the needs of the Special Operations Task Group deployed in Afghanistan, to minimise dependence on allied aircraft for overwatch and ISR. The RAAF ended up joining the Canadian lease with MacDonald Dettwiler and Associates, who were contracted to provide a set number of flying hours' worth of capability. Although an armed Taranis stealth UAV was initially considered (as armed capability was part of the operator demand), the decision was made to lease the Heron for two reasons. First, it was a rapid pathway to ISR capability; second, the ADF could leverage Canadian experience with the system as an exemplar, minimising training and integration barriers. Another likely factor was that the use of armed UAVs in the mid-2000s was (and to an extent remains) ethically problematic and the subject of deep public distaste following the US campaign of targeted killings and signature strikes. There would likely have been serious questions raised about whether the ADF would be able to gain social licence to use armed UAVs in Afghanistan. Critically, for the purposes of this analysis, this lease of the Heron was not initially intended as a pathway to permanent procurement; it was intended purely to meet an operational demand as a stopgap.[48] Another notable RAAF adoption of UAVs was the MQ-4C Triton, an unarmed HALE UAV designed for strategic maritime surveillance. This acquisition was intended to supplement the long-range maritime surveillance capability provided by the P-8A Poseidon.[49] This capability is currently in the process of entering service and will be operated by the re-activated 9 Squadron.[50]

Identified Successes and Barriers to Scalable Adoption

The most important lessons from this case study are that operationally urgent demands from deployed soldiers is the most effective driver of rapid acquisition, and that it is possible for Defence to quickly acquire emerging technology at scale. Supplying ISR with the Heron provided sufficient capability such that the RAAF did not feel forced into acquiring an armed UAV by operational demand. In the absence of an active operational environment to provide this 'forcing function', Defence has, to an extent, lost the overarching incentive to overcome adoption barriers, even where the lack of capability entails the acceptance of operational risks.

There are several barriers to adoption that can be identified from this case study. These include situations in which the innovation is not perceived as part of the organisation's critical task focus, the organisation's perception of its core mission and its approach to achieving it.[51] In this case, the Army recognised that the ability to identify enemy positions, and the ability for infantry to see over the next hill, were both key to its critical task, to fight and win conflict in the land domain. As a result, the organisation was well situated to support the development and integration of tactical-level UAVs in response to an identified operational need.

Following the withdrawal of Australian forces from Afghanistan in 2017, the RAAF dispatched personnel to train in the US in advance of a planned acquisition of an MQ-9 Reaper variant. This initially was considered a positive step forward for the RAAF in procuring this type of capability, especially when initial International Traffic in Arms Regulations (ITAR) and Missile Technology Control Regime (MTCR) restrictions were resolved and US Congressional approval for the export was achieved. Unfortunately, no procurement eventuated. Indeed, despite explicit calls for armed remote and autonomous systems in the 2020 Force Structure Plan and 2016 Defence White Paper,[52] the project has repeatedly been unsuccessful in securing sufficient resources through the force design process. For example, the Sky Guardian project (considered the evolution of the Reaper procurement plan) similarly did not result in procurement of capability, with funds being shifted to other internal Defence priorities. The RAAF has instead focused its advocacy on capabilities related to fifth-generation fighter aircraft. This was also noted as a factor in RAAF's limited engagement with UAVs for strategic lift capability.[53]

There are a number of potential reasons to help explain why armed UAVs were not acquired. These are based on military innovation theory and the experience of comparable militaries. They include:

- Provision of armed close air support with UAVs was not part of RAAF's critical task focus and thus was not prioritised.
- Such assets were not sufficiently advocated for, and were thus unsuccessful in seeking funding through the force design process.
- There existed a cultural aversion to armed UAVs, and/or ethical concerns about their use.
- Intra-service dynamics and path dependency resulted in services advocating most strongly for conventional platforms that fulfil similar functions (such as attack helicopters and Super Hornets).

Each of these challenges, which persist, could start to be mitigated by the early designation of a joint capability manager. This is a step that was recently flagged in the DSR for the space domain.[54] Such an initiative would reflect a recognition of the value of a centralised capability development and management function for these capabilities that have utility beyond the domain within which they may be relegated. For example, while UAVs are an air platform, they have utility within the land and maritime domains. Thus the generation of a joint capability manager would create a central point of advocacy and expertise within the ADF to push, in the case of RAS, autonomous capabilities into the force design process and generate accountability for their implementation wherever they are needed.

Military Case Study Two: DEWs in the US

Despite immense and sustained funding over the past 40 years, the US has still not developed a DEW that can be deployed at scale by any of the service branches, although there have been recent promising small-scale examples. As this is a technologically focused innovation, tied directly to a key offset strategy, it provides a useful case study for understanding pathways towards scalable autonomous systems. In addition, both DEW and RAS innovations have been the subject of multiple hype cycles, and there exists deep circumspection among senior military leaders regarding their respective utility. In the case of DEWs this suspicion is arguably more justified as such projects 'have over-promised and under-delivered for decades'.[55] Reviewing these technologies is timely as both have recently been declared among the six initial priorities of ASCA.[56]

Reviewing the literature and ongoing open-source efforts in this field, it is possible to group barriers to adoption of DEWs into the three technological, organisational and resource categories. In the first category,[57] the main barriers include the interrelated difficulties in test and evaluation, and the scalability of training, which are subject to additional technical and regulatory restrictions relative to conventional systems.[58] One of the main complications is that lasers do not run out of momentum and drop. Further, developers must be cautious not to violate the international ban on blinding laser weapons. Indeed, the danger involved in firing a laser into the air or beyond the horizon is high enough to require that each such test is subject to a risk analysis prior to authorisation. This process is already complex enough in the case of limited testing and validation efforts by military laboratories. One can only imagine, therefore, the challenges entailed in upskilling sufficient personnel to scale any such capability across the US military.

A further issue with DEW technologies relates to their size, power and weight restrictions.[59] Although the development of solid-state lasers promises lower size, weight, power and cooling requirements, their integration still requires careful forward planning in the capability development process.[60] Furthermore, DEWs are overly hampered by adverse environmental conditions, and are reliant on fragile and sensitive componentry that necessitates a sterile clean room for maintenance.[61] It is worth noting, however, that despite these limitations it is nevertheless technologically feasible to deploy some form of DEW in a static land-based position in a more limited role (such as counter Uncrewed Aerial Systems (UAS), albeit this is an inefficient option.

In addition to the challenges of developing doctrine and procedures, organisational challenges include a lack of sustained senior leadership commitment outside of the US Army,[62] and a reluctance among decision-makers (both commercial and military) to invest sufficient resources in the absence of 'near-perfect' versions of the technology.[63] The prevailing sentiment that DEWs have repeatedly promised to be a silver bullet in the future, pending further technological developments, is a significant barrier to securing funding and effort for developing currently feasible systems. There is an obvious parallel here to autonomous systems.

Finally, resource barriers include extremely high initial development and testing costs, which prevent new entrants into the market.[64] The Government Accountability Office recently attributed the expense to the 'relatively low number of initial development efforts'.[65] In effect, the burden rests with the US Government to fund and generate research. However, financial support has been dropping in recent years, to the point where by 2019, the US Government only provided around 20 per cent of research and development (R&D) funding. The market is further skewed by the absence of civilian use cases, preventing developers from offsetting their risk with alternative customer bases and disincentivising new entrants.[66] These interactions create a self-defeating cycle denying emergent economies of scale, which is unlikely to be broken without significant and sustained senior leadership from the US Department of Defense (DoD) and industry.

Commercial Case Study One: Use of UAVs for Conservation and Environmental Management in the US and Australia

The use of remote piloted aircraft has been prominent in conservation, agriculture and environmental management. For example, the US Department of the Interior makes extensive use of UAVs for environmental management and fire surveillance.[67] Such systems are generally cheaper and simpler to operate than inhabited aircraft, lowering the entry barriers for civilian researchers, farmers and government officials to conduct persistent, granular surveillance. UAVs also offer high-resolution surveillance with less disruption (to habitats, for example) and are particularly valuable in inaccessible terrain.[68] While such systems have begun to be widely adopted by individual researchers,[69] there are still resource barriers, a level of cultural aversion and misconception about their value.

The first barrier to adoption is technological. Commercial UAVs have a smaller payload capacity than their military equivalents and therefore need to make a trade-off between battery supply and endurance (in terms of both control range and flight time). There is also a regulatory incentive to keep commercial UAVs below a certain weight to avoid additional regulatory restrictions.[70] Further, while a range of sensors are utilised (including thermal and chemical), they are generally of low quality and smaller (due to limited payload capacity). While balanced by cost savings, such restrictions limit the use cases for potential adopters. More advanced commercial platforms (particularly those with high-resolution imaging and sensors), or data processing software, are significantly more expensive than 'hobby' low-end platforms.[71]

Relatedly, the data collected by such systems is only useful if it can be analysed and interpreted. Acquiring the software and human expertise to analyse captured data can be a significant impediment for individual operators, although it is less of a barrier for well-resourced research institutions.[72] Regulations are another restriction on their use,[73] especially by individual researchers or farmers. In Australia, for example, you cannot operate more than one drone at a time, and it must remain within a visual line of sight, below 120 metres, and more than 5.5 kilometres from controlled airspace. Further, it cannot be flown over a populated area, and can only be operated during the daytime.[74] While exceptions can be granted, use of commercial UAVs is generally associated with the need for additional training and pre-flight approvals in a complex process that could deter small-scale adopters. Safety concerns (to oneself, property, bystanders, or even other aircraft) are also a deterrent factor, particularly for users who are not experienced and licensed UAV pilots.[75] Finally, as with any surveillance of wildlife, there are risks involved in relying upon UAVs.[76] Numerous studies have been conducted on the potential impacts of such systems on the behaviour of diverse animal populations, from Antillean manatees[77] and dolphins[78] to bears.[79] This risk of environmental harm could thus further disincentivise adopters with a duty of care to animal populations.

Commercial Case Study Two: Use of Robotics in the Construction Industry Worldwide

The construction industry is an enduring and important sector globally, accounting for between 9 per cent and 15 per cent of GDP in most countries.[80] Although challenged by a series of interlinked issues including skilled labour shortages, high safety risks,[81] and the need for increased productivity, the sector has traditionally shown a reluctance to invest in emerging and unproven technologies. Robotics offer significant potential productivity benefits, with the range of demonstrated use cases ranging from exoskeletons through to brick-laying robots. However, while there have been some instances of adoption, significant barriers remain. Most of these barriers are related more to the nature of the industry than to the technology itself, an aspect of the case study that makes it particularly valuable for this analysis.

Among the most significant barriers to new entrants are the high initial capital and operating costs associated with both acquiring high-capability robotic systems and implementing them into business practices.[82] Even if a firm is willing to take the financial risk in becoming an adopter, there are limited suppliers of such systems, restricting their geographic diffusion.[83] This situation is further exacerbated by the fragmented nature of the construction industry, which detracts from any sector-wide effort to lower implementation costs or standardise maintenance.

Furthermore, the sector faces challenges with skilled worker shortages,[84] with existing workforces generally having low levels of technological literacy.[85] While incorporating such technologies into initial staff training or qualifications is the most efficient way to resolve this issue,[86] this is particularly challenging in the construction sector. For example, the traditional apprenticeship model, even with a basis of initial vocational education, is currently ill-suited to rapid acquisition and diffusion of the key cognitive skills needed to effectively integrate RAS.[87] As the gap between the technology and average worker skill base increases, it becomes exponentially more difficult to overcome. A lack of familiarity with the technology, its technical reliability and its value proposition also has a detrimental effect on key cultural factors, including trust and acceptance.[88] In the absence of significant public-private investment in improving training for both apprentices and existing construction workers, it is unlikely that robotics literacy will significantly improve in the medium term.

It is also worth considering the lack of awareness of the potential value proposition of these technologies, or experience with their use, among construction firm leadership, particularly around cost, installation time and technology development trends.[89] This reduced awareness disincentivises pre-emptive workforce investment and organisational change. As with any disruptive innovation, organisational practices must adapt to make the most effective use of technology.[90] For example, the introduction of exoskeletons or on-site additive manufacturing would have significant regulatory, safety and practical implications for how construction firms plan and build structures, their timings and their costings. However, such technologies would also require workers to be trained in their effective use and see shifts in supply chain management practices, with potential job losses. The latter relates to the additional barrier of needing to convince unions of the benefits of robotics and overcoming their resistance to technologies that could replace their members.[91] Each of these challenges is slowing the implementation of robotics in the construction sector, particularly in less advanced and less well-educated economies.

Survey of RAS-Specific Barriers in Military Organisations

This section identifies several potential barriers associated with the adoption of RAS. These barriers are compiled from a review of the scholarly literature, including previous reports written by RAND for the Royal Australian Navy (RAN) that were focused on enabling innovation with, and rapid acquisition of, RAS-AI capabilities in the near and medium timeframes. The purpose of this review of the broader literature is to identify specific barriers that have been invoked in relation to limited successes in the adoption of military RAS.

Resource and Technological Barriers

There are inherent materiel challenges associated with the widespread diffusion of RAS in military organisations, including (but not limited to) technical capabilities and associated supports, as well as the allocation of appropriate financial resources. Indeed, this occurs even in countries where there has been sizeable expenditure and where technical and industrial capabilities are advanced.[92] For example, the US DoD invested US$9.6 billion on RAS technologies in 2019, followed by an additional US$4.6 billion in 2020.[93] Thus, as with DEWs, it is apparent that significant monetary investment is necessary but insufficient to push this innovation to a demonstration point.

Furthermore, while smaller, uninhabited systems can fulfil certain missions at a lower cost than their traditional crewed equivalents, there are important caveats. These include technical complexity in terms of computing power and data collection/distribution components within size, weight and power demands. Further, the need to operate in challenging environments requires significant investment.[94] Training the AI programs that allow for fully autonomous functionality has steep entry barriers, consuming vast amounts of energy, water and computing power.[95] Although duplicating such a system is significantly less resource intensive, a first mover must overcome these initial barriers.

In addition, the underlying technology has not matured to a point where a ‘near-perfect’ lethal autonomous weapons system (LAWS) could be developed that would meet the reliability, explainability and safety requirements that any sensible and ethical military would demand.[96] Moreover, the reliance of autonomous systems in terms of software, computing, signal communications and connectivity generates vulnerability to an array of countermeasures, as well as cyber security issues including hacking, jamming and 'spoofing'. Addressing these vulnerabilities results in the growth of both the complexity of the systems and the unit costs.[97]

Testing, Evaluation, Validation and Verification

Testing, evaluation, validation and verification (TEV&V) continues to be 'the principal means of demonstrating a program's readiness for deployment',[98] determining that the system will reliably operate in the manner intended.[99] However, there are inherent difficulties related to AI and RAS, which can act in undesirable or unpredicted ways.[100] Significant RAS TEV&V challenges include the complex, and often hidden, interactions between system elements, behaviour and performance. For example, an unexpected behaviour could be the result of a hardware fault, a data issue, a misaligned sensor, malicious or inaccurate algorithms, or simply an emergent behaviour of a fully autonomous system.[101] There is also complexity in translating idealised training datasets into real-world replicable testing and training environments, and in determining how to effectively verify and validate the training data on closed systems.[102] The non-deterministic nature of some AI-based systems means that TEV&V systems must somehow account for emergent behaviours, post-fielding learning and changes,[103] and the convergence effect (where integrating AI has unexpected effects at the system level).[104]

RAS also presents challenges to developers' attempts to conduct experimentation and evaluation efforts. The potential for such systems to act in unexpected ways raises a risk to both testers and bystanders. A potentially unreliable armed or mobile platform represents a highly asymmetric threat function,[105] requiring stricter testing range restrictions. Complex systems have a tendency to fail spectacularly and destructively, usually with little obvious warning.[106] Examples of this risk involving RAS include a 2007 incident where a South African anti-aircraft cannon malfunctioned and targeted its own crew, killing nine and wounding 14.[107] Fragmentation of the TEV&V process and lack of appropriate test facilities may diminish the ability to institute the requisite lesson-learning mechanisms.[108] The latter is a key barrier for the ROK, for example.[109]

Assessing RAS performance currently requires slow and costly field testing. That testing can only capture small snapshots of performance rather than assess mission-level performance,[110] and it does not necessarily account for post-deployment learning. Additionally, there are challenges in integrating potentially hazardous early RAS into non-controlled exercises alongside human soldiers. This situation limits the potential to achieve the exposure necessary to encourage development of new concepts of operation.[111]

Procurement and Acquisition Challenges

Several aspects of RAS differ substantively from more traditional military capabilities. These include the dual-use nature of underlying technologies, the need to train the enabling AI, and the supply chain risks. These factors 'necessitate a variety of novel processes, more rapid acquisition, prototyping and fielding',[112] and have led to infrastructure, acquisition and integration barriers. First, an 'autonomous system' is not a traditional stand-alone capability that can be prioritised in a straightforward manner under existing ADF acquisition processes; rather it is a class of technology. Its distinguishing feature—the capability to operate outside of direct human control—is based largely on AI, an enabling technology closer to electricity,[113] rather than a traditional system component (such as a higher calibre weapon). Furthermore, RAS can take significantly different forms (from weapon systems to logistics transports, to digital assistants), and are guided by still-emerging operational concepts. Taken together, these features impose additional challenges and barriers in the way of effective acquisition processes, especially at early TRL.

Procurement challenges are further exacerbated by the fact that responsibility lies with multiple actors across different stages of the defence capability life cycle. The UAV case study demonstrated how this could lead to inconsistent adoption across the ADF. This factor complicates the existing known challenges in achieving a rapid and effective defence capability life cycle, a situation which leads to significant delays in transitioning innovations through to scalable acquisition.[114]

There is also the persistent post-demonstration ‘valley of death’ problem.[115] Fortunately, the fact that RAS are reliant on dual-use technologies and the subject of active commercial interest means that with RAS, unlike DEWs, the military can piggyback to an extent on commercial actors. Accordingly, there have been numerous efforts to bypass traditional military development and acquisition processes to overcome the valley of death for autonomous systems. These initiatives include the US Defence Innovation Unit (DIU) and Joint Artificial Intelligence Center (JAIC), the UK’s jHub program, the Canadian Innovation for Defence Excellence and Security (IDEaS) program, and Australia’s ASCA.

The fact that each of these agencies is orientated towards commercial and non-traditional defence innovators is not a coincidence. It is reflective of a recognition that RAS cannot be ‘owned’ by the military in a traditional capability sense. RAS development relies instead on significant engagement with industry, academia and the entrepreneurial community. The DEW case study is demonstrative of the value of such systems being dual-use in nature. A civilian market ameliorates risk and lowers entry barriers, while defence investment can help entrants remain viable, particularly with low-TRL inventions. While there have been concerted efforts to draw in these stakeholders, there continues to be disagreement around technical and operational requirements, as well as military aims.[116] Consider the reluctance among a significant number of civilian researchers with regard to the US military’s autonomous weapon system related research.[117] This misalignment is exacerbated by challenges associated with getting RAS technologies ‘inside the tent’ when they are most advanced in the commercial sector.

Organisational Challenges

Successful adoption of novel military innovation requires significant organisational change capability.[118] As with any large institution, militaries develop organisational practices and cultures that reinforce existing ways of achieving defined strategic goals (whether that be delivering long-range fires or cornering the market on digital watches). Disruptive innovations such as RAS are particularly difficult for such organisations to adopt at scale because they require significant organisational change.[119]

The first organisational barrier to RAS relates to a willingness and capacity to experiment with emergent technologies and concepts. During the incubation period, where the ‘invention gains influence via advocacy

[and] experimentation',[120] strong and sustained leadership and strategic guidance are needed to support experimentation. Without a coherent strategy regarding the characteristics of scaled RAS across the organisation, demonstrating its importance will be difficult to achieve, and there will not be the requisite protection from competition with regard to other priorities.[121]

An essential task in successfully moving through the incubation period, and a core component of a military's capacity to adopt such innovation, is its ability to generate an effective operational praxis that capitalises on the disruptive impact of that innovation.[122] To achieve this requires realistic and iterative experimentation both in the real world and through modelling and simulation (M&S), a requirement that is particularly important in the absence of a successful first mover who can be emulated. As noted in the Australian Army Robotics and Autonomous Systems Strategy v2.0, M&S activities play an important supporting role. In a similar move, the RAN recently updated its M&S strategy, with support from RAND Australia, as well as its Fleet Warfighting Plan. The UK and US militaries have also invested in similar M&S.

However, such activities should only be viewed as supportive elements within the effort to develop an operational praxis, particularly if one wishes to generate asymmetric advantage. To more directly address the requirement of operational praxis, a number of militaries have developed, or are developing, dedicated experimentation units for RAS. These initiatives go beyond M&S to specifically address issues such as the loss of momentum and knowledge when introducing a new capability into service. For example, in 2022 the ROK stood up the 'Tiger Demonstration Brigade' with the explicit purpose of experimentation and integration of emerging autonomous systems and military AI.[123] Establishing this unit allowed the ROK military to focus specialised permanent personnel and equipment in a unit that could be given regulatory waivers and sustained funding.[124] In effect, this allowed them to sidestep the main barriers to their engagement with autonomous systems sufficiently to enable the conduct of bottom-up experimentation within the microcosm of this specific unit.

The British Army has taken this force structure approach one step further with the establishment of a dedicated Experimentation and Trials Group. This group contains infantry, armour, combat service support, artillery and engineers Trials and Development Units which are tasked purely with field experimentation in conjunction with the UK Defence Science and Technology Laboratory (Dstl) and industry partners.[125] The final, and potentially most disruptive, element of this group is the 2nd Battalion of the Yorkshire Regiment, which has been designated as the Army's Experimentation Battalion. Its primary focus is now on live experimentation, integration of equipment, and emergent doctrine in pursuit of human-machine teaming praxes.[126]

The literature on military innovation suggests that a clear commitment by senior leadership to experimentation with RAS will have a strong impact on military capability. As demonstrated by the UK example, effective leadership supported the British Army to successfully adopt RAS, and fostered its capacity to achieve organic bottom-up innovation. Continuation of this level of organisational commitment will be crucial to the British Army's efforts to maintain an operational advantage over less agile adversaries. The Australian Army could likely generate similar benefits through the establishment of its own dedicated experimentation unit. Such a unit would only need to be of relative comparable scale to either of the preceding examples. For example, the Army could leverage existing special operations units, the permanent cadre in its reserve formations, or even Force Surveillance Units.

More broadly, inoculating the Australian Army in the use case for autonomous systems, and their value proposition, requires that experimentation is paired with 'appropriate codes, practices, and doctrines' as well as 'a competent workforce organized in suitable formats'.[127] Developing these capabilities requires that senior decision-makers are given frank and expert advice on the likely capabilities of such systems, realistic timelines for their maturation, and clear evidence concerning how RAS are likely to shape the future battlespace. Again, M&S can support these requirements, although generating asymmetric advantage over an adversary—which is also evolving its engagement with these systems—requires that the Army is able to draw on a strong and dedicated operations analysis capability.

While developing this specialised operational praxis is a key component, it is challenging to achieve in the absence of a forcing function. Generating such impetus requires organisational structures that encourage experimentation and risk taking, both characteristics which are important for establishing trust and familiarity with emerging technology. A strong leadership signal in experimentation and operations analysis would likely be an important step towards achieving scalable adoption. An additional challenge, however, is the need for skill sets that are beyond those met by the traditional skill base and that incur non-traditional cognitive demands.[128] Military organisations rely on 'base-fed workforce models'. Therefore, they may struggle to access and retain new skill sets[129] and may also encounter pushback from personnel who are concerned about job displacement.[130] Finally, as with armed UAVs and the US Air Force (USAF),[131] there are cases in which a cultural aversion develops against the use of the innovation. This aversion can act as a barrier to adopting certain innovations where they do not align with the dominant view of the organisation's core purpose (for example, whether an air force run by pilots should invest in uncrewed platforms).

Overall, significant support is required for RAS-specific organisational frameworks such as a skilled workforce, processes which preserve organisational knowledge,[132] and a culture that tolerates new ways of work. If failure is perceived as non-performance,[133] creative RAS-related solutions and innovative pathways may be impeded.[134] Unless there is an organisational culture that embraces new ways of working and adopts appropriate levels of risk, the capacity for diffusing RAS will be limited. Expectation of ongoing success encourages the pursuit of short-term benefits at the expense of more impactful longer-term accomplishments.[135]

Perceived Advantage and Actual Benefit

Meaningful adoption requires a clear and rigorous view of perceived relative advantage, and awareness of the value of the technology, when weighed against costs and the ability to integrate and effectively exploit it.[136] This includes establishing realistic perceptions of what RAS can achieve, as well as a discerning approach to the projected abilities and limitations. As seen in the armed UAV and robotics in construction case studies, it is difficult for organisations to develop a specialised operational praxis for the use of emergent innovations in the absence of experience with such systems. To some extent decision-makers can draw on experiences with precursor innovations (such as UAVs in this case),[137] and operational experience could be gained if the technology (or representatives of it) is utilised in realistic training scenarios (as opposed to mere demonstrations).

While RAS offers obvious and manifold benefits, usability and empowerment of the war fighter and the force must be the priority. Disruptive technology is not a positive advancement if that disruption results in a reduction in the capability of the force to fight.[138] Indeed, in some cases, RAS are being used as ‘an expensive acquisition hedging strategy’, with investment occurring across ‘a wide array of mission sets and capabilities’, rather than being properly integrated into carefully prioritised areas of expected operational advantage. The resultant expense may potentially distract from higher utility applications[139] or may damage trust in the technology among decision-makers (as seen in the US DEW case study).

Legal and Ethical Concerns

The use of fully autonomous systems in military domains, where there may be targeting or live fires, has engendered ethically confronting ideas about meaningful human control.[140] These issues are most prominent in the context of the legality of autonomous warfighting under international law, especially with regard to lethal applications.[141] Key ethical issues associated with RAS include the protection of people, society and the environment; algorithmic bias and discrimination; explainability, reliability and accessibility; accountability and responsibility mechanisms; and privacy and transparency.

There is also a prevalent ‘asymmetry objection’ to RAS.[142] Originally raised in relation to remote systems, it argues that using such systems is immoral because they create ‘radical asymmetries of risk’.[143] Specifically, the user leverages superior technology to inflict damage with no risk to their own personnel.[144] Opponents of RAS assert that it enables the user to remove risks while they impose violence on another human. This concern has been challenged in academic literature[145] as well as by the US military.[146] The persistence of the ‘killer robot’ idea, and fears that the use of RAS lowers the threshold for escalation of conflict due to dehumanisation of the use of force,[147] has driven years of negotiations under the auspices of the United Nations, one outcome of which was the development of a norm promoting meaningful human control across all critical functions, regardless of the benefits of automation.[148] Unfortunately, there remains no universally accepted definition of LAWS; nor has there been agreement at a sufficiently granular level as to what would constitute ‘meaningful human control’.

If RAS are increasingly deployed in sensitive military environments, the lack of established norms around their use and reaction raises the risk of unintended escalation.[149] However a promising indication that escalation can be avoided can be seen in the 2019 shooting down of a US Global Hawk by Iran. Here, non-violent de-escalation was ultimately achieved, which would not have been possible with an inhabited platform.[150] This gives rise to the complex issue of how to assign state responsibility for a breach of international law when there is an unintentional breach of sovereignty caused by a machine.[151] The dual-use nature of some RAS, and their ubiquity in non-military roles, has also made development of strict regulatory controls or international governance frameworks challenging.[152] This situation may incentivise states to integrate RAS without instituting policies that ensure the requisite safety and reliability of systems. Non-regulation of RAS risks a 'race to the bottom' in state practice and undermines the primacy of human agency.[153]

Trust and Acceptance Issues

Trust remains a foundational issue for the acceptance of RAS and, therefore, its ubiquity and/or normalisation across a military organisation. One of the key barriers to trust arises in relation to human-machine teams where common goals between operators and the RAS are not well defined, where interfaces are ineffective, or where the RAS may be 'operating on different contextual assumptions of the operational environment'.[154]

There is also concern around the risk of moral injury associated with the widespread incorporation of RAS into military capability. Such concern is based around the study of cognitive processes that guide humans away from behaviour that they believe is inconsistent with their moral and ethical standards.[155] More particularly, research has shown that people have a propensity to 'ignore data that may challenge their core identity' as part of a process of 'identity-protective cognition' which is an accepted human self-defence mechanism.[156] There are also compelling arguments that receptivity to RAS cannot be explained by demographic, organisational or capacity-based theories. A study found that operators on the ground perceive drones as less trustworthy than crewed aircraft simply because they prefer 'the "warm fuzzy" of human interaction'. [157] In the absence of sufficient trust, militaries may be forced to limit themselves to semi-autonomous or supervised autonomous systems, reducing the technology's potential impact. While exercises, testing and experimentation are vital to building trust and familiarity, early testing could damage trust and place soldiers in danger, particularly as there exists no theoretical way of predetermining the system's exact behaviour, coupled with risks of erroneous or even maliciously altered system components.

These issues of trust and acceptance are complicated by the fact that militaries of liberal democracies need to retain social licence to legitimise their activities, particularly the use of force. As is evident from the backlash against the US armed drone strike program which began in Yemen in 2002,[158] and the continued myth of killer robots, mistrust could be a genuine barrier to ADF adoption of RAS in the absence of a powerful public use case.

Developing a Comprehensive List of Potential Barriers for ADF Adoption of RAS

From an examination of the case studies above, six key barriers to adoption have been distilled. It should be noted that overlaps exist between each of these barriers and it has not been possible to canvass all issues relevant to the adoption of RAS within the scope of this analysis. Furthermore, within each case study, barriers (or references to them), while having the same title, may describe different issues. For example, within the construction case study, barriers associated with 'introduction into service' were related to workers understanding the rationale behind the introduction of RAS, rather than any technical issues. This issue is quite different to what 'introduction into service' means in military or defence settings, which is more closely related to technical and TEV&V requirements.[159] And while there exist training and education activities to overcome the resistance to introduction of new systems or ways of working, the costs associated with such activities in turn can be seen as barriers. This is especially true in examples such as the construction case study, where opportunity for business leaders to just improve understanding of emerging technologies was limited.

In summary, understanding and measuring barriers to adoption of RAS is a complex endeavour. Nevertheless, this analysis has sought to identify a range of specific barriers (and has provided titles to describe them) in order to begin to clarify those factors that are likely to impede the broad adoption of RAS by the ADF. As noted in the methodology section, further investigation is needed to further rationalise and quantify barriers before practical efforts can be made to overcome them.

Resource Requirements

The issue of resource liability was a dominant one within the case studies. This was especially the situation in the commercial case studies, where higher-cost robotics attract higher barriers to adoption than lower-cost robotics.[160] Costs include those involved in the acquisition of the technologies as well as in their subsequent maintenance. The dual-use nature of key RAS-related technologies, and the potential economic benefits of developing domestic production capabilities, can somewhat offset these costs. Such offsets are an important incentive for investment by industry, as demonstrated by the impact of their absence in the DEW case study. However, such benefits are difficult to calculate—as indeed is the calculation of the full costs—given that upskilling or training of staff and new infrastructure are often needed to realise the full benefits of the technology. An example of effective cost offsetting can be drawn from the ROK. Specifically, the South Korean Government provides tax credits to companies that invest in new equipment. This initiative has helped the ROK become one of the world's largest adopters of robotics with 1,000 robots installed per 10,000 employees.[161;162]

Technology Complexity

The case studies all demonstrate that increasingly complex tasks attract correspondingly more complex technologies. Similar to the demands placed on militaries, the construction industry requires technology that is robust, flexible, highly mobile and versatile in its deployment. The evolution of the technology, once deployed, must be in step with the evolution of the processes for its potential future use. In addition to these challenges, the normal hurdles of technology development persist. These relate to characteristics such as size, power, weight or the ratios between them. While technology must be robust, its use must also accommodate fragile and sensitive componentry. These competing needs were a clear barrier to adoption in the DEW case. Further, cyber security adds an additional level of technological complexity. This is because RAS depends not only on the availability of data but also on the generation of it for the purposes of subsequent decision-making.

Understanding the costs of technology presupposes a clear understanding of what technologies are available. In the commercial case studies, just getting information on new technology—specifically cost, installation time, developments and trends—was difficult. It was noted that industry stakeholders had fewer opportunities to attend conferences where this information was presented. Conversely, their own industry conferences focus most heavily on careers, skills, training and industry development. Technical barriers associated with procurement processes arise due to the challenges of understanding the complex technology first, while simultaneously assessing the subsequent costs it may impose.

Experimentation, Exercises and TEV&V

The previous analysis has highlighted the challenges associated with TEV&V for RAS. While this is a necessary requirement (barrier) to achieve introduction into service of a capability, it is suggested that experimentation and exercises are equally important to the demonstration of a program's readiness for deployment. This is especially the case when the RAS technologies being considered challenge traditional ways of fighting. In operation, each of these activities provides an opportunity to address technological issues. For example, it is possible to generate a greater understanding of the technology itself, as well as the necessary supporting/enabling functions. TEV&V also provides a direct opportunity to address incompatibilities between old practices and new technologies, and to gain insights as to what shifts in tools, techniques and procedures (TTPs) may be required to optimise use of the technology. For the successful conduct of exercises, or any of these activities, integrated teams need to be brought together. Nevertheless, while militaries may be willing to undertake such activities, their coordination and inevitable cost pose multiple significant organisational barriers. In addition, the opportunity for commercial contenders to access TEV&V may be limited.

While barriers to technology adoption undoubtedly exist, the ADF could mitigate them by accepting the need to routinely plan for TEV&V in order to achieve better warfighting capabilities. Such an approach would enable the organic evolution of the technologies, and their shepherding through their entire life cycle. The reset could be driven by the maintenance of a core integrated team with oversight across all activities. Here the Army's Robotics and Autonomous Systems Implementation and Coordination Office (RICO) provides an excellent example. We also suggest that the focus of technology demonstration or 'showcase' activities should be warfighting, rather than technical ingenuity. Pointing to or emphasising more the ultimate application of the technology, rather than demonstrating the performance of the technology against certain (usually limited) out-of-context tasks, could provide the necessary forcing function to drive real change.

One final point is that integrated TEV&V may have the added benefit of making entry into (and exit from) different funding streams or capability processes less problematic and burdensome for the ADF. It would thus alleviate one of the most substantial barriers to RAS adoption that currently exists. For example, Autonomous Warrior is listed as an exercise for the

Navy.[163] Information pertaining to the event refers to *testing, demonstrating, TEV&V,* and *showcasing* of capabilities, and notes that it is an important step in the process for the ADF to take advantage of RAS technologies.[164] However, successful technology demonstrations by combined industry and ADF teams at such exercises do not necessarily translate into ability to win the next level of funding. Indeed, stakeholders must often re-prosecute their business case with the next Defence agency, such as the Defence Innovation Hub, even when support from the ADF end-users exists.[165;166]

As was outlined in the introduction to this paper, the newly announced DSR initiatives pertaining to the Capability Acquisition and Sustainment Group (CASG) and ASCA seek to address issues related to testing and evaluation as well as the acquisition process. Such mechanisms must be informed by TTPs that reflect a specialised operational praxis. While the development of such TTPs, and doctrine more broadly, is the domain of the Army, there is a danger that stove-piping these activities will entrench, rather than overcome, existing testing and evaluation barriers. As previously discussed, this risk might be mitigated (to an extent) by the appointment of a dedicated joint capability manager.

Cultural Aversion

Present in every organisation, cultural aversion involves a preference for former and proven solutions. As cited in the construction case study, one reason for such aversion is the volatile and unpredictable nature of the environment. Similar attitudes prevail within the military, particularly within a war setting. The aversion to failure that permeates these institutions drives a demand for near-perfect technologies before investment. These demands may also reflect a desire to understand what the technologies will or will not do and to thereby minimise the risks associated with them. While perfection and risk minimisation are important considerations, they should nevertheless be balanced against each other.

Strong leadership commitment to new technologies can help ensure similar commitment from operators. This is particularly true for military organisations with their traditional hierarchical structures. Demonstration of commitment requires constant messaging and the provision of a rationale as to why new technologies must constitute part of force structure (or workforce) going forward. The privileges of leadership should be exploited to overcome barriers, such as funding, and to support myriad activities and facilitation around barriers (both perceived and actual). Importantly, leaders need to provide the assurance operators need that their genuine efforts to adopt new technologies, if unsuccessful, will not result in adverse career outcomes.

Supported by strong leadership, consistency and constancy assists organisations to overcome thresholds of cultural aversion. The 2017 USMC initiative 'Quads for Squads' provides a useful example. Pushed by the Commandant of the Marine Corps at the time, nearly 600 tactical drones were delivered to Marine infantry squads. These were initially issued for trial and experimentation to improve situational awareness for troops on the ground.[167] However, the program was almost stopped nine months into the trial over cyber concerns.[168] By 2020, the USMC plans still existed to evolve their uncrewed capability. The concept was to issue small UAVs (Group 1 capabilities) to ground combat elements, resident within their manoeuvre units, using Reapers to perform strike missions at the Group 5 level.[169] How many of the initial 600 drones remain in service is unclear, but the USMC does remain committed to using this capability. In April 2023, trials of a new tactical resupply uncrewed aircraft system (TRUAS) were reported. This TRUAS drone is highly automated and not manually flown, allowing for efficient tactical resupply missions for Marines in combat.[170]

Despite the importance of ADF leadership in paving the way for new technologies, the adoption of RAS at scale nevertheless remains elusive. It is true that successful deployment of UAVs has occurred when the demands of the situation (and the end-users within that situation) have identified this technology as the best fit-for-purpose solution. We suggest that these situations evidence a forcing function through which the technology is demonstrated as a useful, better capability against a critical task focus. Outside of these situations, without such a forcing function, questions remain as to what critical or other purpose RAS serve. Ships and planes during peacetime serve diplomatic and deterrence purposes. They are synonymous with their respective services (as tanks or the infantry soldier are with Army). By contrast, fleets of RAS do not attract or possess the same gravitas; nor has their criticality been demonstrated—at least not to a sufficient threshold of organisational experiential understanding. Therefore, their role may continue to reside in a limbo space, acquired in response to a time-limited organisational need. Consequently, most users will not develop the vital first-hand experience of the potential of RAS beyond that offered by existing capability. Aspirations to rewrite doctrine, concepts of operations, TTPs and the like will not be realised and adoption at scale will not be achieved.

In the absence of real progress before now, the question arises as to where a forcing function may emerge sufficient to overcome the ADF's entrenched obstacles to RAS adoption at scale. The answer may lie in the DSR. Importantly, by describing Australia as finding itself in a radically new strategic position, the ADF has been provided with a propitious forcing function by government. The impetus for the ADF to change now exists. It has been directed to reorganise and reprioritise so that it is postured to meet imminent (in this decade) contingencies and/or commit to a long game with other democratic nations to defeat anti-liberal nations in their attempt to disrupt international order and geopolitical stability. Further, the DSR emphasises the need to generate asymmetric advantage, where the ADF 'pit[s] strength against weakness, at times in a non-traditional and unconventional manner, against which an adversary may have no effective response'. Such a directive presents itself as a written order for the widespread adoption of RAS capability.[171] This is especially so given that, as this analysis has demonstrated, no nation appears to have successfully deployed RAS at scale, including those that might compete with Australia in the Indo-Pacific. The threat of war and the challenge of asymmetry may have long-ranging implications for force posture and design, and provide a prime opportunity for Australia to gain operational tempo over potential adversaries. By overcoming its barriers to adoption at scale, the ADF can render asymmetric advantage over others still struggling to overcome their own barriers.

Training and Workforce

Training is an important metric for determining rates of acceptance and adoption. The greater the departure from existing concepts of operation the technology requires, the greater the training that will be required to reach full adoption. Investment in training requires recognition within the organisation of the need for the pursued capability, together with the need to prepare personnel for its use. This is a lower burden in the case of a known technology, where the military is training people towards a specific method of warfare.

Specialist workforce generation and retention is a known and significant issue for the ADF. The challenge of how to generate subject matter expertise and experience in a competitive and resource-constrained environment has encouraged a number of overseas militaries to consider moving away from closed and generalist workforce models. For example, the USMC has mooted lateral entry mechanisms that would allow civilians with strong cyber skills to be appointed at a comparable rank.[172] More broadly, the US military is considering how to harmonise talent pipelines within the organisation so that individuals are organisationally incentivised to build and maintain particularly relevant experiences and training,[173] potentially reflected in specialised job codes.[174] These discussions reflect a realisation that generating expertise in designing, integrating and leading future human-machine teams is vital for successfully generating asymmetric advantage in their use.

If the ADF were to move towards a professional development continuum that trains people to adapt, or to have capacity to adapt, then the workforce may be much better poised to deal with uncertainty and risk. This uncertainty and risk should be recognised and accepted as a characteristic not only of the battlefield but also of the technology. Linked strongly to the technological barrier, it is difficult to design the perfect capability solution. While it is possible to approach design as being integrable (across tasks and people, and with the use of other capabilities), it is important to recognise that the final 20 per cent of the solution may only become apparent within an operational setting. Further, this 20 per cent may need to remain ‘tuneable’ to the setting, or against evolving technology.[175] Being trained to adapt, as well as being trained with the 80 per cent solution, will allow the capability to be optimised in its use against the known specificity of a critical task focus. It is fair to say that not all technologies or capabilities afford such opportunities. Yet examining small RAS (or Group 1 to 3 capabilities as the USMC defines them)[176] may nevertheless be eminently achievable.

While training, in general, addresses workforce skills and gaps, skills shortages become inevitable unless that training also delivers technological awareness. Therefore, military professional development should encompass education with respect to emerging technologies, including both what they involve and the capability they can deliver. Possessing this deep understanding of the initial emerging technology situates both the future operator and the developer with a much clearer picture of what capability can or will be realised and how it can be used or adapted.

Ethical and Legal

As discussed earlier, ethical and legal issues persist and are often canvassed as providing rationales for distrust of certain RAS applications. But just as operators' distrust may be overcome through training, exercises and other activities, there must also be evidence that legal and ethical considerations have been designed or built into new systems from the outset. Such systems could include moral and ethical 'tripwires' that require human input in all targeting decisions alongside the demand for appropriate levels of human responsibility, authority and control.[177] While desirable, such assurances may not be guaranteed when the ADF adopts commercial off-the-shelf systems. In these cases, the full range of relevant technical, regulatory and ethical standards may not have been considered during the capability's design and development phases. Regardless, ethical, legal, procedural and governance considerations need to be constantly scrutinised by the ADF, with systems implemented for determining agreed levels of risk.

State Capacity and Barrier Evaluation

Understanding why no state has been able to adopt fully autonomous systems at scale requires an acknowledgement of the complexity, and variability, of the interaction between capability and barriers. It is not just the challenge of generating sufficient capability or maturing technology to a set tipping point; nor are the barriers universal in their height or application. Instead, analysis of capability must be merged with considerations of the unique 'demand' of each stakeholder, the level at which they determine that a barrier has been overcome, and the initial operating capability to be achieved.[178]

The following section examines both capacity and barrier conception in seven overseas countries. Capacity is assessed based on a modified version of adoption-capacity theory.[179] In addition to resource capacity (including financial intensity, domestic military industrial base, foreign arms acquisition) and organisational capital capacity (critical task focus, level of investment in experimentation, organisational age),[180] this analysis considers organisational innovation factors including the receptiveness of domestic audiences, the strategic environment, and the capacity to develop or emulate specialised operational praxis. For example, while the US has a significant lead in resource capacity, its pursuit of future fully autonomous platforms—which can operate in denied environments—means that it is pursuing capabilities that require higher levels of cost and technological sophistication (albeit it is also pursuing some less sophisticated capabilities as well). Relative to this, Singapore, for example, is not pursuing the same level of technological sophistication, at least not on its own. Instead it will adopt sophisticated technologies when they are available, and in a manner consistent with its resource capacity. Interestingly, both these nations may be situated as far away from realising adoption at scale of RAS as each other, but for quite different reasons.

The second element of this section is an assessment of the sensitivity of each exemplar state to each of the barriers identified in the consolidated list above. The purpose of this analysis is to illustrate variance in sensitivity to potential adoption barriers, and the influence of this variance on when the barrier can be considered to have been met. For example, South Korean civilians have a greater collective acceptance of military robotics than Australian civilians, demonstrating a higher level of receptiveness of the civilian population (leading to a higher capacity). Further, the South Korean military has demonstrated a willingness to operate alongside supervised autonomous systems, such as the SGR-A, indicating a lower level of cultural aversion to new technology.

It is important to note here that different methodologies were used for each element of this analysis. The adoption capacity of each state was assessed empirically, based on the factors identified above. By contrast, the barrier sensitivity evaluation was based on an initial distillation of information gathered through a limited open-source analysis. A deeper understanding of the interaction between these elements, and recommendations for addressing them in the Australian context, would be valuable avenues for future research.

Australia

Australia embraced the utility of UAVs with the rise of counter-insurgency operations in the 21st century. A 2004 UAS Roadmap provided a plan for the ADF's adoption of such systems. Under this framework, remotely piloted systems, ranging from small, hand-launched systems for small infantry tactical utility, up to strategic platforms such as the MQ-4C Triton, have been pursued by the ADF for the purpose of ISR support.[181] While the ADF's experience started with uncrewed systems, innovation was subsequently boosted with the establishment of the Trusted Autonomous System Defence Cooperative Research Centre (TAS-DCRC) from 2018. As experience has increased in remote operations of mostly aerial systems, the ADF is increasingly considering more sophisticated platforms that introduce autonomous functions.

Capability Overview

To date, systems used by the ADF have been remotely operated at the bottom level of the RAS autonomy spectrum. However, such experience has provided a precursor to systems that will have lesser human roles. Boeing's MQ-28 Ghost Bat UAV, Anduril's Ghost Shark Uncrewed Underwater Vehicle and the Ocius Bluebottle represent systems that have some level of autonomy that will be networked with ADF platforms. Additionally, there are high levels of innovation arising within Australia's defence industry, from the attritable Wanderer UAV[182] to the ground attack STRIX UAV, and the experimental DART AE hypersonic platform. In the commercial world, there is strong maturity of remotely operated and autonomic platforms in all three domains, especially supporting the resources sector.[183]

Barrier Sensitivity

Australia's R&D investment has reduced relative to GDP over the past decade and compared to other OECD nations.[184] Australia has also spent less on defence R&D, both as a share of GDP and as a share of government R&D funding.[185] Defence R&D has been allocated primarily through the Next Generation Technologies Fund (for lower TRL) and the Defence Innovation Hub (for higher TRL). Australia has experienced valley of death issues with innovation programs in the past, like many other nations, hence the establishment of ASCA, which is meant to address this resource shortfall.[186] ASCA funding will be focused on specific capability priorities, which may overcome a barrier if RAS capabilities are included within these priorities. Thus, it is fair to predict that targeted investment in RAS capabilities, especially in pull-through of innovations, will significantly reduce adoption barriers.

While a wide range of universities and industry participants are engaged with Defence through the DSTG and single-service initiatives such as RICO, the breadth of technologies and Australia's limited capacity mean that it is not possible to achieve the depth of expertise required for innovation across all technology areas. Accordingly, it would be difficult for Australia to intervene sufficiently to overcome the technology complexity barrier. However, targeted investment in key technologies, in conjunction with a burden-sharing arrangement such as AUKUS, will help overcome this barrier.

Australia's approach to testing and evaluation is predominantly tied to platform-centric funding, with limited capacity to verify and validate emerging technologies.[187] Establishing trust in the behaviour of an autonomous system is thus challenging. It is difficult to measure predictability in a system that may not act in an obviously deterministic manner.[188] Although Defence has recognised this challenge, with its internal strategy and efforts from the TAS-DCRC, interventions to overcome this barrier will take time.

cultural aversion is a problem for most organisations, but particularly so within the ADF given its age, traditions, and command and control structures.[189] This habitual reluctance to change is further complicated by a known entrenched tendency to adopt low-risk approaches (in processes, doctrine, training and structure).[190] While capability development processes no longer presume a replacement philosophy, the capacity to adopt innovations (given their higher risk profiles) remains low. There is nevertheless a promise to overcome this barrier, through the DSR's emphasis on change, asymmetric advantage, establishment of the ASCA, and intent to change risk appetite in acquisition.[191] Further, as demonstrated by the ADF's rapid adoption of UAVs for situational awareness in the Middle East, the ADF can quickly embrace change where there is clear operational need and urgency. Nevertheless, our assessment is that this represents a significant barrier for Australia.

The ADF has traditionally claimed that training and the professionalism of the workforce are a potential source of relative advantage. Yet reducing levels of STEM education in Australia, together with increasing competition for technology jobs, will mean that the workforce will remain a barrier to RAS adoption.

ADF-affiliated ethicists have clearly argued in support of subjecting new defence systems to a high level of ethical scrutiny, in the same way that technical risks are reviewed.[192] Any acquisition of RAS by the ADF would be required to comply with established international humanitarian law. Compared to nations with different ethical thresholds, having such requirements and establishing such processes could be seen as diminishing the ADF's capacity to adopt innovation and to overcome barriers. However, we would contend that these requirements reinforce the effective adoption of RAS technologies, even though they do represent a higher barrier to adoption than may be experienced in other countries. Prioritising ethics in engagement with RAS has the important benefit of buttressing the ADF's capacity to gain social license for their use, and as a preventative measure against moral injury.

United States

The US has clearly and repeatedly stated its strong interest in acquiring scalable autonomous systems. Such systems were central to the Third

Offset Strategy. Military applications of AI, including LAWS, were also major aspects of the National Defense Authorization Act, an executive order in 2019. Such technologies have also been extensively discussed in strategic and doctrinal publications across the US DoD.

Adoption Capacity Overview

As expected the US continues to be the leading investor in technologies related to AI and autonomous systems, particularly in the military domain. Focusing on recent funding, the 2020 defence budget allocated US$3.7 billion for research related to uncrewed and autonomous systems, and a further US$927 million for research into AI.[193] This followed the investment of US$18 billion over the 2016–2020 period (in 2016 dollars).[194] These investments were supported by the creation of the JAIC (intended to create a critical mass of expertise to rapidly identify, prioritise and operationalise AI research efforts across the DoD) and the DIU (essentially a physical DoD outpost in Silicon Valley intended to encourage startup-led rapid defence innovation).[195] Outside of pure monetary investment, the US is able to draw on top-level talent, generating the most AI-related publications in 2019 for example,[196] and a commercial sector with a strong venture capital environment and deep investments in relevant technologies.[197] However, the US is hampered by a strong reluctance in the civilian research sector to participate in military AI research,[198] most publicly demonstrated by the public outcry of Google staff regarding Project Maven. Ironically Maven continues today, with progress being made by companies backed by venture capital investment funds.[199] This reluctance is likely to persist, given the current public debates among US lawmakers regarding what guardrails to apply to AI generally, and its potential for 'discrimination, misinformation, and invasion of privacy'.[200]

Barrier Sensitivity

The US places a significant premium on technological reliability, complexity and rigorous testing. While admirable, this approach leads to a risk of 'gold plating' and long procurement and acquisition pipelines for traditional military equipment. This is a challenge that the US has recognised—it was a core driver of the Third Offset Strategy—and is attempting to mitigate through organisational efforts such as the DIU. Furthermore, US military innovation efforts have historically been delayed by high organisational barriers, which range from cultural aversion (in the case of armed UAVs and the USAF), through to reluctance to invest sufficiently in emergent but imperfect technologies (such as DEWs). Finally, as with the ADF,[201] the US military still holds itself to strong legal, ethical and safety requirements, which are reflected in the latest version of the Directive 3000.09.[202]

China

China has clearly indicated its interest in autonomous systems and AI. Interestingly, its position on a pre-emptive ban is far more complex than those of the other countries listed here. Specifically, while China has officially declared that it supports a ban, the details of its position paint a different picture.[203] Despite this, the Peoples Liberation Army (PLA) has recognised the importance of these systems in disrupting the conventional military superiority of the US,[204] and they are a core feature of the Chinese view of intelligentised warfare.[205]

Adoption Capacity Overview

Although specific figures on military R&D expenditure are imprecise and often unavailable, it is clear from open-source literature that Chinese investment in relevant technologies has been rapidly expanding and rivals that of the US in key areas.[206] China has publicly announced its intention to become the leader in global AI development by 2030.[207] Supporting this aspiration, Chinese institutions started securing comparable engineering university rankings to the US as early as 2017.[208] This fact is often lost in the narrative surrounding China's real and sustained intellectual property theft campaigns.[209] What is noteworthy, however, is that China's capacity to innovate is weighed down by a weakening economy and a culture of hierarchical risk aversion.[210] The extent to which China has overtaken the US in key technologies is debated, but the contest is clearly close.[211]

Barrier Sensitivity

Based on open-source analysis and literature, China appears to be working towards comparable organisational and resource standards to those of the US. China's resource investments are believed to be lower than but comparable to those of the US.[212] The organisational barriers to implementing such systems effectively (including the development of a specialised operational praxis) remain largely comparable to those in the US, although the PLA is culturally, politically and structurally significantly less capable of encouraging the bottom-up innovation necessary to overcome those barriers.[213] Where there is a significant differentiation is in technological, legal and ethical barriers.[214] The PLA is unlikely to adopt the same international legal and Western ethical standards. As with the US,[215] China has demonstrated the capacity and willingness to engage in military activity despite it being in violation of international norms (in the South China Sea, for example). Finally, while China has some advantages as a disruptive rising power, Chinese autonomous systems would need high capability to prosecute great power conflict, yet China's development efforts continue to (overall) lag behind the US's.

Republic of Korea

South Korea has a strong interest in autonomous systems and is currently developing concepts for their operation as well as making investments in relevant development efforts. Autonomous systems are central to South Korea's Defence Innovation 4.0 concept.[216] South Korea is among the more unlikely leaders in autonomous systems, with an economy of comparable size to Australia's but a strong strategic imperative for LAWS and rising arms exports.

Adoption Capacity Overview

South Korea has invested heavily in AI and autonomous systems.[217] Its government is also able to draw on a strong civilian research sector (across both universities and defence companies) that does not have the same cultural aversion as we see in the US.[218] The ROK's defence base is further supported by a push for funding AI research by the government and a growing share of the regional arms export market. There are no major domestic organisations opposing the use of RAS by the military, and trust in AI is generally quite high. There is also greater familiarity with the technology, with the ROK having the highest robot-to-human ratio in the world.[219] The ROK Government has also released guidelines for promoting ethical AI development[220] and co-sponsored the 2023 Responsible AI in the

Military Domain conference. This suggests that the government is actively considering how to ensure safe and ethical development of military AI. Finally, there is a strong recognition of the importance of AI to its critical task (deterring North Korean (DPRK) aggression).[221]

Barrier Sensitivity

Despite these capabilities, however, barriers remain that South Korea is attempting to address. Although arguably similar in terms of barrier perceptions, where the ROK differs from Australia is in its capacity. The ROK military struggles with a culture that is averse to risk and the cost of breaking things. This risk aversion is not helped by South Korea's reliance on conscripts, reinforcing a mindset of avoiding problems.[222] This leads to a level of organisational inertia, which is what drove the establishment of experimentation units for RAS. The ROK also has difficulty meeting testing and evaluation standards for AI, with limited facilities in which to test systems without human risk. Furthermore, the absence of a numerical reliability benchmark encourages decision-makers to leave AI in the 'nice to have' basket, in a similar manner to US decision-makers' approach to DEWs. Like Australia, the ROK has more limited resources than the US or China, yet its military is geared towards a more narrowly defined core task, limiting dilution of effort.

Israel

Despite its comparatively small size, Israel has emerged as a leading exporter of armed remote piloted systems and is believed to be heavily investing in increasingly autonomous systems. In a similar manner to the ADF, the Israel Defense Forces (IDF) is interested in RAS based on a desire to offset its smaller size and to reduce risk to its personnel while still delivering lethality.[223] It is notable that the IDF is one of the few states to have deployed RAS.[224] The IDF uses the Guardium UGV[225] to patrol its Gaza border,[226] and there is ongoing debate as to how to categorise loitering munitions such as the Harpy and the Harop.[227]

Adoption Capacity Overview

Although its exact investment in military R&D is not publicly available, Israel does prioritise such investment and the country is known to have significant innovation capability. Such innovation is driven in part by an enduring ‘siege mentality’ that deeply affects Israeli defence planning and acquisition.[228] Interestingly, and informatively, given its position in the remote piloted aircraft market, the Israeli defence industry has become increasingly export orientated, pursuing innovation to retain and expand its market position.[229] The three main defence companies (all state-owned) are supported by a technologically competent commercial sector and one of the most STEM-literate populations.[230] Israel also deliberately fosters a culture of improvisation and invests heavily in ‘crash’ programs to meet emergent capability needs. Commanders are encouraged to accept ‘80 per cent solutions’ when delivered at speed.[231] In essence, the IDF has created its own enduring forcing function, reinforced by a cultural paradigm based in perceived constant threat.

Barrier Sensitivity

An open-source assessment of Israel’s engagement with autonomous systems suggests lower organisational,[232] legal and ethical barriers,[233] combined with strong technological capacity[234] and organisational agility.[235] That said, there are resource constraints in place that hamper Israel’s efforts: the economy is not comparable to those of the great powers and to a large extent is reliant on exports.[236] The combination of these factors imposes constraints as market demand incentivises proven technologies and capabilities (such as remote piloted aircraft and loitering munitions).

United Kingdom

The UK has repeatedly expressed interest in AI and autonomy as core emergent military capabilities. Based on a review of the literature, the UK is deeply interested in military applications of AI, particularly autonomous systems. Interestingly, the UK has defined autonomous systems based on whether they are ‘capable of understanding higher-level intent and direction’,[237] distinguishing them from automated systems that are ‘programmed to logically follow a predefined set of rules’.[238] This makes the UK’s definition of autonomous systems notably narrower than that of the US and arguably defines away the problems with autonomous weapon systems in the short term.[239]

Adoption Capacity Overview

The UK invests the most in military R&D of any country in Europe, a significant portion of which has been either committed to AI research or ring-fenced for similar technologies. For example, Dstl committed approximately US$21 million to autonomy projects between 2010 and 2017.[240] The UK is also able to draw on a strong commercial research base in these areas, including firms such as QinetiQ and BAE.[241] In addition to resource capacity, the UK Ministry of Defence (MOD) has established several bodies to promote RAS adoption (both internally and with civilian partners).[242] In addition, the Defence and Security Accelerator[243] has held multiple innovation challenges and competitions related to RAS and AI, supporting commercial innovation in the space. Finally, the MOD can draw on the Development, Concepts and Doctrine Centre, an internal think tank) for conceptual and strategic thinking that feeds into both doctrinal and procurement decision-making.[244] It is notable, however, that UK and EU researchers disproportionately oppose military applications of AI, complicating efforts to best utilise the civilian research sector.

Barrier Sensitivity

In terms of barriers to adoption, the UK has similar perceptions to Australia of the technological, legal, ethical and resource considerations. However, as the UK has a larger military with a commitment to great power conflict, its engagement with autonomous systems is more focused on autonomous warfighting capability than the ADF's interest in enhancing and augmenting human capabilities. The UK believes that autonomous weapons systems can be utilised ethically and legally under its current 'approach to the delivery of AI-enabled capability in Defence' but has notably limited itself to not creating or using systems that 'would operate without meaningful and context-appropriate involvement throughout their lifecycle'.[245] It is thus committing itself to the expense and complexity of sophisticated autonomous platforms that retain appropriate human controls.

Singapore

In a similar manner to the ADF, the Singapore Armed Forces (SAF) has a deeply enshrined belief that technological advantage is necessary to offset its smaller size and (for Singapore) lack of strategic depth. Furthermore, Singapore has taken a pragmatic approach to its defence industrial base, focusing on maintaining its systems, upgrading foreign-purchased systems, and securing niche development and manufacturing capabilities. Given these factors, Singapore has unsurprisingly expressed interest in acquiring RAS-AI enabled systems.

Adoption Capacity Overview

The SAF is generally considered to be the best funded and equipped of the South-East Asian militaries. This is the result of a combination of consistent military spending, a strongly hierarchical and controlled society, and multiple linkages to an advanced, innovative civilian economy.[246] The SAF is well funded by regional standards, with military R&D accounting for roughly 4 per cent of the defence budget in 2018 (roughly US$340 million) and procurement accounting for an additional 13 to 16 per cent of the budget.[247] This expenditure is supported by a strong industrial base, which has been referred to as the SAF's 'fourth service' branch[248] and has developed a reputation for successfully upgrading, maintaining and retrofitting advanced systems.[249] Importantly, given the SAF's hierarchical organisational culture, autonomous systems feature prominently in the Next-Generation SAF transition plan.

Barrier Sensitivity

Singapore's adoption capacity may be comparatively high in the regional context; however, it faces key barriers that are of particular interest to Australia. Most importantly, the SAF has demonstrated a hierarchical top-down organisational culture and a preference for evolutionary development. While it has consistently achieved success in incremental innovation when directed to do so, or when an ally can be emulated, organisational culture is a clear cultural barrier to radical innovation. The establishment of the Future Technology and Systems Directorate, with a mission to encourage disruptive thinking in the SAF, is a promising step towards a resolution. Singapore's military spending is dwarfed by the great powers and its industrial base is not structured to support radical innovations in high-end warfighting platforms. This suggests that Singapore is well positioned to be a fast follower, rather than a leading first mover outside of niche capacity, which is a position that Australia would also be well suited to adopt.

Initial Comparative State Analysis

Based on the analysis of each nation above, Figure 1 (the 'spider chart') illustrates the sensitivity of each state to barriers relative to the other states. The further the nation's position is from the centre, the more sensitive the nation is to that barrier, making it more difficult for the nation to overcome. Sensitivities to a range of barriers are derived from the fact that each barrier individually needs to be overcome to realise adoption of the capability. Given their default position, some nations have to work harder to overcome some barriers than others.

These assessments of sensitivities are informed judgements based on an initial distillation of open-source information. For the purpose of this analysis, they were approached in a normalised fashion—that is, no adjustments for difference in the desired target RAS capability levels were made, even though these target levels vary significantly between the nations. Viewing the spider chart, differences and similarities in barrier sensitivity can be more readily observed between each nation or state. For example, we can observe that Western nations appear to be much more sensitive to ethical and legal barriers. To counter the apparent simplicity of Figure 1, an explanation of the highest barrier sensitivities for each nation follows. The sources informing the relative positions of nations within the spider chart are diverse, even when nations have been assigned the same value for sensitivity against a barrier.

Figure 1: Barrier Sensitivities for a Range of Nations Source: RAND

The most significant barriers to Australia's engagement at scale with RAS relate to its smaller resource capacity, acquisition pathway challenges, and workforce challenges. As a middle power military with a smaller industrial base than the US, the ADF's capacity to be a first mover is limited by its comparative resource restrictions. This barrier is further exacerbated by known challenges in the Defence acquisition process, overcoming which was one of the key incentives for the creation of ASCA. Another significant barrier for Australia is workforce: in the absence of strong leadership direction, emergent capabilities are limited by the internal competition for personnel in an environment characterised by recruitment and retention challenges. Finally, while not a 'barrier' in the same sense, the ADF holds itself to a high ethical and legal standard, which necessarily translates to more stringent expectations of an autonomous system in terms of safety requirements and safeguards.

The US's efforts to adopt RAS at scale are being largely delayed by its pursuit of near perfect technologies. This is being abetted by organisational risk aversion, which overall results in difficulty transitioning prototypes to capability without exorbitant costs. These costs are not helped by struggles in engaging elements of its domestic innovation base and limited competition in the military industrial base.

China’s aspirations are comparable to those of the US in terms of what it envisions for its future first-generation RAS. While it also invests similar monetary resources, China has strong disincentives limiting its cultivation of top-level talent in key industries. This has served to inhibit its overall technological progress, which seems to ultimately lag behind that of the US.

While the ROK enjoys the world’s highest rate of adoption of robots across industry, adoption of RAS within its military is being held back by training and organisational agility issues. Difficulty in acquiring sufficient training facilities, reliance on short-term conscripts, and a risk-averse organisational culture combine to make barriers even more problematic against the ROK’s comparative resource scarcity.

Israel’s high-risk appetite is illustrated by its acceptance of 80 per cent solutions for the temporal advantage they offer. However, while this puts Israel ahead in terms of realising its own RAS capability, it unfortunately does not support Israel’s pursuit of export sales of RAS technologies, as in other countries the sensitivities to ethical and legal barriers are much higher. The relatively small size of Israel’s economy (compared to those of great powers) and the dependence on market exports means that it has limited resource capacity to pursue fully autonomous weapons systems as far as it would like.

The key issue preventing the UK from successful adoption appears to be its sensitivity to ethical and legal barriers associated with autonomous weapon systems, together with a comparative deficit between its resource capacity and its desire for high-complexity systems.

Singapore’s lower resource and technological capacity arguably prevents it from being a first mover. While this is somewhat offset by its high cultural acceptance and more limited adoption aims, the persistent aversion or organisational resistance to more revolutionary development means that it will not field RAS before others have successfully done so.

Overall, Figure 1 serves to illustrate how collectively none of the nations studied have been able to adopt RAS at scale, even though their individual reasons or sensitivity to barriers diverge. If nothing else, this finding emphasises the complexities of the problem. A more detailed assessment is required to fully understand all that is occurring here. Understanding in a more quantitative manner where Australia sits in terms of its sensitivity to barriers would help target efforts to overcome these barriers. In addition, Australia’s position relative to other nations (especially like-minded nations) serves to identify opportunities to overcome barriers where they either don’t exist or are minimised for other nations. Conversely where similar barriers do exist, an examination of the measures those nations are applying to overcome them would prove equally informative. Some of these measures have already been noted in the preceding evaluation section.

Conclusion

While every major military has publicly declared an interest in RAS, no documented wide-scale deployments of weapon systems exist that are truly robotic and functionally autonomous. This paper has identified an initial list and undertaken a preliminary evaluation of what the potential barriers to the adoption at scale of RAS may comprise.

A range of states were examined to understand their adoption capacity in terms of overcoming each of these barriers based on their security threat environment, their resource capacity (which includes military expenditure, organisational capital capacity, and receptiveness of domestic audience towards RAS), and finally their capacity to develop or emulate a specialised operational praxis (the process by which militaries translate capability into effect) for the use of RAS. The differences between each state illustrate the complexities in evaluating both the sensitivity to barriers and the adoption capacity in a predictive manner. While time and budget constraints limited the authors' capacity to consider these issues in close detail, the analysis nevertheless affords the following useful initial insights against which the subsequent recommendations are made.

Key Findings

From the analysis presented in the paper, the following key findings emerge:

- This examination highlights that consistent barriers to adopting emerging innovations at scale exist in both civilian and military organisations.
- Key RAS-related barriers comprise ethical and legal issues, trust and acceptance challenges, cultural aversion, resource requirements, training and workforce constraints, and technological complexity.
- Examination of a range of nation case studies highlights that each nation exhibits different sensitivities to each of these barriers.
- Understanding the interaction between capacity and barriers of a given state is a complex but vital task if barriers to adoption of RAS at scale and speed are to be overcome.

- A forcing function, such as operational necessity, has historically proven decisive for successful deployment of uncrewed systems. This is an organisational factor and largely technology agnostic.
- In the absence of active operations, this forcing function could be replicated through realistic warfighting exercises and experimentation, which contribute to the experiential learning necessary for adoption at scale.
- Beyond this, a joint capability manager for RAS, and similar assets that have application across many warfighting domains, is needed to ensure these assets are afforded appropriate prioritisation in planning, acquisition, training and deployment processes.
- In articulating the heightened strategic competition, especially within the Indo-Pacific, the DSR provides the overarching impetus required to address all the above issues.

The identified barriers across each stage of the research are summarised in the table below.

Summary of Barriers Identified in Phase One[250]		
Barriers Noted in the Adoption Case Studies	RAS-Specific Barriers	Combined Barrier List
ADF UAV adoption • Perceived advantage / actual benefit **DEW in US military** • Technological (test and evaluation, training also noted) • Organisational • Resource (including absence of commercial market) **UAV for conservation** • Technological • Regulatory • Safety • Environmental risk **Robotics in construction** • Cost • Implementation difficulty • Industry fragmentation • Training • Perceived advantage / actual benefit	Resource and technological TEV&V Procurement and acquisition Organisational Perceived advantage / actual benefit Legal and ethical Trust and acceptance	Resources Technology complexity Experimentation, exercises, training, evaluation Cultural aversion Training and workforce Ethical and legal

Next Steps / Recommendations

Based on the key findings above, the following actions are recommended to be undertaken by the ADF:

- A more complete examination and application of adoption capacity theory and barrier analysis to determine approaches for overcoming the key Australian barriers identified in this report.
- Investigation of the extent to which Australia's national industrial base can be leveraged to overcome key barriers.
- Detailed evaluation of the progress made by comparator nations towards overcoming key barriers to adoption, and evaluation of how those lessons could be applied to Australia.
- Evaluation of potential experimentation unit models in the context of ADF capacity and requirements.
- Consideration of mechanisms for the ADF to encourage and support small-unit experimentation with RAS.
- A detailed evaluation of RAS as an avenue towards securing asymmetric advantage in the land domain.
- An in-depth review of organisational models for successful integration of RAS.

About the Authors

Dr Marigold Black is an intellectual historian with expertise in geopolitics, strategic level defence and national security issues. She was previously a Strategic Policy and Futures Research Fellow with the Australian Army Research Centre and the Strategic and Defence Studies Centre at the Australian National University, where she has undertaken extensive studies in sovereignty and the levers of national power, and worked with the Army to advance its intellectual strengths as part of the Joint Future Force. At RAND, her work has included addressing sovereign outcomes within the Guided Weapons and Explosive Ordnance Enterprise, military deterrence signalling, defence mobilisation planning, and human-machine interface (HMI)/workforce studies for Navy's future use of RAS. She has also conducted research on insider threat to assist the practitioner community in building strategies for better detection, management and prevention; was involved in innovative research on countering online violent extremism; and has provided support to the Department of Foreign Affairs and Trade in training development for countering foreign interference. Marigold has a PhD in history from the University of Sydney.

Dr Andrew Dowse has been director of RAND Australia since July 2021. In this role, he identifies policy research opportunities for Australian clients at the Commonwealth and state/territory levels, delivers and disseminates high-quality research and analysis on Australian policy issues, and leads the RAND Australia office in Canberra. His most recent work for RAND Australia has been in providing research support to the Australian Department of Defence, specifically the Sovereign Guided Weapons Enterprise and the National Naval Shipbuilding Group. Before joining RAND, he was the director of defence research at Edith Cowan University, with responsibilities including cyber research. Prior to that, he served in Defence with senior appointments in integrated capability development and plans, including all cyber-related projects in Defence's Integrated Investment Program, and as the head of ICT Operations and J6. He retired from active duty in 2018 at the rank of Air Vice-Marshal. His research interests include information warfare, military strategy, defence capability and technologies, national security and space. Dowse holds a PhD in information science from the University of New South Wales.

Dr Joanne Nicholson joined RAND Australia in July 2019 after 20 years' combined experience working in and across government, industry and academia, particularly in support of defence, national security and the intelligence community. As a highly experienced operations researcher, strategic analyst and futures specialist, Joanne works with a variety of agencies to ensure their investment programs are aligned to relevant and appropriate strategic objectives and designed to deliver the benefits that their organisations are seeking. She has extensive experience in technology forecasting and horizon scanning as well as related policy implications. At RAND her research has included supporting the Royal Australian Army and Navy in examining the role future technology and future thinking has within their organisations. She has also worked with both the Defence Science and Technology Group and the National Security Science and Technology Centre to identify critical technologies and opportunities for application of AI. Joanne holds a PhD in physical chemistry from Flinders University of South Australia.

Dr Austin Wyatt joined RAND Australia in 2022. His research focuses on the impacts of emerging and disruptive critical technologies, with a particular focus on AI and autonomous systems. While at RAND, Austin has contributed to research supporting the ADF in its engagement with emerging technologies. He holds a PhD in political science from the Australian Catholic University, which was awarded summa cum laude and received the Vice Chancellor's Award for Excellence in Doctoral Research. Prior to joining RAND Australia, Austin held research positions at the Australian Catholic University and UNSW Canberra. Austin is the primary author of a number of academic publications, including a book entitled *The Disruptive Impact of Lethal Autonomous Weapon Systems Diffusion: Modern Melians and the Dawn of Robotic Warriors*.

About RAND Australia

This work was conducted by RAND Australia. RAND Australia is RAND's Canberra-based subsidiary that analyses defence, national security, economic and social issues for Australian clients. With a commitment to core values of quality and objectivity, RAND Australia combines local research talent with world-class experts from across RAND's global presence to solve complex Australian public policy problems. For more information on RAND Australia or to contact our director, please visit www.rand.org/australia.

Funding

This research was sponsored by the Australian Army.

Acknowledgments

The authors would like to thank Brigadier James Davis (DGFLW), Colonel Robin Smith (Director RICO) and Lieutenant Colonel Rachael Ayoub (Centre of Land Autonomy Lead) for providing us with the opportunity to engage in this exciting work and for their ongoing engagement and feedback as the research progressed. We would also like to thank our colleague Dr Lyndal-Joy Thompson for her useful contributions to the research involving the commercial case studies. Finally, we would like to thank Dr Carl Rhodes and Dr Jonathan Wong for their thoughtful and extremely useful review of this report.

Abbreviations

ADF	Australian Defence Force
AI	Artificial intelligence
ASCA	Advanced Strategic Capabilities Accelerator
CASG	Capability Acquisition and Sustainment Group
DEW	Direct energy weapon
DIU	Defence Innovation Unit
DoD	(US) Department of Defense
DSR	Defence Strategic Review (2023)
DSTG	Defence Science and Technology Group
DSTO	Defence Science and Technology Organisation
Dstl	(UK) Defence Science and Technology Laboratory
EU	European Union
GDP	Gross domestic product
HMAS	His Majesty's Australian Ship
IDF	Israel Defense Forces
ISIS	Islamic State
ISR	Intelligence, surveillance, reconnaissance
JAIC	Joint Artificial Intelligence Center
LAWS	Lethal autonomous weapon systems
MOD	(UK) Ministry of Defence
OECD	Organisation for Economic Co-Operation and Development
PLA	People's Liberation Army
RAAF	Royal Australian Air Force
RAMSI	Regional Assistance Mission to Solomon Islands
RAS	Robotics and autonomous systems
R&D	Research and development
RICO	Robotic and Autonomous Systems Implementation & Coordination Office
ROK	Republic of Korea
SAF	Singaporean Armed Forces
STEM	Science, technology, engineering and mathematics

ADF	Australian Defence Force
TAS-DCRC	Trusted Autonomous System Defence Cooperative Research Centre
TEV&V	Testing, evaluation, validation and verification
TRL	Technology Readiness Level
TTPs	Tools, techniques and procedures
UAS	Uncrewed aerial system
UAV	Uncrewed aerial vehicle
UGV	Uncrewed ground vehicle
UK	United Kingdom
US	United States
USAF	United States Air Force
USMC	United States Marine Corps

Endnotes

1 M Raska and RA Bitzinger, *The AI Wave in Defence Innovation: Assessing Military Artificial Intelligence Strategies, Capabilities, and Trajectories*, Taylor & Francis, 2023.

2 A Wyatt, *The Disruptive Impact of Lethal Autonomous Weapons Systems Diffusion: Modern Melians and the Dawn of Robotic Warriors,* Routledge, 2021.

3 MC Horowitz, 'Artificial intelligence, international competition, and the balance of power', *Texas National Security Review,* vol. 1, no. 3, 2018.

4 V Boulanin, 'Mapping the development of autonomy in weapon systems: A primer on autonomy', *Stockholm International Peace Research Institute,* 2016.

5 Boulanin, 2016.

6 RICO, 'Robotic and Autonomous Systems Strategy v2.0', Australian Army Future Land Warfare Branch, 2022.

7 P Scharre, *Four Battlegrounds: Power in the Age of Artificial Intelligence,* WW Norton, 2023.

8 PW Singer, *Wired for War: The Robotics Revolution and Conflict in the Twenty-first Century,* Penguin Press, 2009.

9 MC Horowitz, 'When speed kills: Lethal autonomous weapon systems, deterrence and stability', *Journal of Strategic Studies,* vol. 42, no. 6, 2019.

10 '2022 USAF & USSF Almanac: Equipment', Air and Space Forces, www.airandspaceforces.com/article/2022-usaf-ussf-almanac-equipment

11 Wyatt, 2021.

12 R Crootof, 'A meaningful floor for meaningful human control'. Temple International & Comparative Law Journal, vol. 30, 2016, p. 53.

13 Wyatt, 2021.

14 S Russell, 'AI weapons: Russia's war in Ukraine shows why the world must enact a ban', *Nature,* vol. 614(7949), 2023, pp. 620–623.

15 Boulanin, 2016.

16 P Scharre, *Army of None: Autonomous Weapons and the Future of War,* WW Norton & Company, 2018.

17 J Kahn, 'A.I. drones used in the Ukraine war raise fears of killer robots wreaking havoc across future battlefields', *Fortune,* 29 March 2022, https://fortune.com/2022/03/29/artificial-intelligence-drones-autonomous-weapons-loitering-munitions-slaughterbots-ukraine-war

18 I Bode, H Huelss, A Nadibaidze, G Qiao-Franco and TFA Watts, 'Prospects for the global governance of autonomous weapons: Comparing Chinese, Russian, and US practices', *Ethics and Information Technology,* vol. 25, no. 1, 2023, p. 5.

19 Boulanin, 2016.

20 A Rossiter, 'Drone usage by militant groups: Exploring variation in adoption', *Defense & Security Analysis,* vol. 34, no. 2, 2018.

21 K Marcinek and E Han, *Russia's Asymmetric Response to 21st Century Strategic Competition: Robotization of the Armed Forces,* RAND Corporation, 2023.

22 Marcinek and Han, 2023.

23 Wyatt, 2021.

24 Ibid.

25 A Wyatt, 'Charting great power progress toward a lethal autonomous weapon system demonstration point', *Defence Studies,* vol. 20, no. 1, 2020.

26 Department of Defence, 'Government announces most significant reshaping of Defence innovation in decades to boost national security', Canberra, 28 April 2023.

27 Department of Defence, *National Defence: Defence Strategic Review,* Australian Department of Defence, 2023 (DSR).

28 As per reference at footnote 27: 'Priorities for the program are hypersonics, directed energy, trusted autonomy, quantum technology, information warfare and long-range fires.'

29 Department of Defence, DSR, 2023, p. 71.

30 J Christianson, S Monaghan and D Cooke, 'AUKUS Pillar Two: Advancing the capabilities of the United States, United Kingdom, and Australia', Center for Strategic and International Studies, 2023. Alternatively see Department of the Prime Minister and Cabinet, 'AUKUS factsheet', undated.

31 JG McGinn and MT Roche, *Developing a 'Build Allied' Approach to Increasing Industrial Base Capacity,* Naval Postgraduate School, 2023.

32 MC Horowitz, *The Diffusion of Military Power,* Princeton University Press, 2010.

33 This theory posits that the 'origin, diffusion and influence of a particular invention cannot be understood except in terms of the total culture which originated or utilizes it'. It is based around three factors: the technological capacity of the identified state, the development of effective military training and doctrine that exploits the advance, and the receptiveness of the domestic sociopolitical and cultural environment to the underlying technology. EO Goldman and RB Andres, 'Systemic effects of military innovation and diffusion', *Security Studies,* vol. 8, no. 1, 1999, pp. 79–125, in Wyatt, 2021.

34 Wyatt, 2021.

35 A more detailed methodological overview can be provided in an annex upon request.

36 K Chávez and O Swed, 'The proliferation of drones to violent nonstate actors', *Defence Studies,* vol. 21, no. 1, 2021.

37 K Joyce, 'Can the Australian Defence Force become the most uncrewed and autonomy-enabled defence force in the world?', in N Townsend, K Pandey and J Pendlebury, eds, *Australian Perspectives on Global Air and Space Power,* Routledge, 2023.

38 K Joyce, 'The Australian Army and unmanned aerial vehicles ... 20 years on and still nothing in service', paper presented at AIAC14: Fourteenth Australian Aeronautical Conference: Royal Aeronautical Society, Australian Division; Engineers Australia, Melbourne, 2011.

39 This proved to be a sound assumption, as Lt Col Frewen recounted: 'People thought [UAVs] could see through roofs and find them hiding in cupboards, that they could read people's minds and know they were having bad thoughts.' See RW Glenn, *Counterinsurgency in a Test Tube: Analyzing the Success of the Regional Assistance Mission to Solomon Islands (RAMSI),* RAND Corporation, 2007.

40 Department of Defence, 'Army delivers final component of Plan Beersheba', 2017.

41 Author correspondence with an Australian official, 27 April 2023.

42 Author correspondence with an Australian official, 28 April 2023.

43 Author correspondence with an Australian official, 27 April 2023.

44 Initially released in 2004, the public version of the Australian Defence Force Unmanned Systems Roadmap was subsequently updated in 2005 and 2006. It planned out an acquisition pathway for an uncrewed aerial system (UAS) over a 20-year period.

45 Joyce, 2011.

46 Ibid.

47 Ibid.

48 The RAAF operated the Heron under this lease arrangement until the end of operations in 2017.

49 Department of Defence, *2016 Defence White Paper,* Australian Government, 2016.

50 J Ng, 'RAAF readies for Triton UAV operations', *Asian Military Review,* 15 June 2023.

51 A prominent example is the difference between the US Marine Corps and the US Army. 'The critical task of the Marines is described broadly as being a "warrior", and the marines envisage all marines as soldiers with rifles first rather than identifying marines by their specific task.' Contrast this with the US Army's focus on 'massing firepower to win conventional wars', which led to lower organisational agility as this focus 'drove its strategy rather than other way around'. See Horowitz, 2010.

52 The potential for acquiring armed UAVs for 'interdiction and close air support' was also noted in the *2013 Defence White Paper* 'subject to policy development and Government consideration'. The value of acquiring UAVs for surveillance has been noted in every white paper since 1994.

53 M Hetherington, *Unmanned Air Mobility for the Australian Defence Force: Future Platforms, Partnerships and Challenges,* Air and Space Power Centre, 2022.

54 See Department of Defence, DSR, 2023, p. 62.

55 SJ Freedberg, Jr, 'The laser revolution: This time it may be real', *Breaking Defense,* 28 July 2015.

56 Department of Defence, 'Government announces most significant reshaping of Defence innovation', 2023. The initial priorities announced in 2023 included hypersonics, directed energy, trusted autonomy, quantum technology, information warfare and long-range fires.

57 'Even after many years of development, there is not a single directed energy system fielded today, and fewer programs of record exist than in 2001. This circumstance is unlikely to change without a renewed focus on this important area.' See CSBA quoting the 2007 Defence Science Board Task Force on Directed Energy Weapons report.

58 J Ludwigson, *Directed Energy Weapons: DOD Should Focus on Transition Planning,* Government Accountability Office, GAO-23-105868, 2023.

59 M Gunzinger and C Dougherty, *Changing the Game: The Promise of Directed Energy Weapons,* Center for Strategic and Budgetary Assessments, 2012.

60 Ludwigson, 2023.

61 Ibid.

62 Ibid.

63 Gunzinger and Dougherty, 2012.

64 Ibid.

65 Ludwigson, 2023.

66 Ibid.

67 ML Bathrick, *Unmanned Aircraft Systems Integration Strategy (2015–2020),* Office of Aviation Services, 2015.

68 LF Gonzalez et al., 'Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionizing wildlife monitoring and conservation', *Sensors,* vol. 16, no. 1, 2016.

69 SE Walker, M Sheaves and NJ Waltham, 'Barriers to using UAVs in conservation and environmental management: A systematic review', *Environmental Management,* vol. 71, no. 5, 2022.

70 Civil Aviation Safety Authority, ‘Drone weight categories and requirements’. As of 2 June 2022, www.casa.gov.au/drones/get-your-operator-credentials/drone-weight-categories-and-requirements

71 Walker, Sheaves and Waltham, 2022.

72 R Adade et al., ‘Unmanned Aerial Vehicle (UAV) applications in coastal zone management—A review’, *Environmental Monitoring and Assessment,* vol. 193, 2021.

73 Ibid.

74 Civil Aviation Safety Authority, ‘Drone Rules’. As of 10 May 2023, www.casa.gov.au/knowyourdrone/drone-rules

75 Walker, Sheaves and Waltham, 2022.

76 Ibid.

77 SS Landeo-Yauri et al., ‘Behavioural and physiological responses of captive Antillean manatees to small aerial drones’, *Wildlife Research,* vol. 49, no. 1, 2021.

78 T Fettermann et al., ‘Behaviour reactions of bottlenose dolphins *(Tursiops truncatus)* to multirotor Unmanned Aerial Vehicles (UAVs)’, *Scientific Reports,* vol. 9, no. 1, 2019.

79 MA Ditmer et al., ‘Bears show a physiological but limited behavioral response to unmanned aerial vehicles’, *Current Biology,* vol. 25, no. 17, 2015.

80 JMD Delgado, L Oyedele, A Ajayi, L Akanbi, O Akinade, M Bilal and H Owolabi, ‘Robotics and automated systems in construction: Understanding industry-specific challenges for adoption’, *Journal of Building Engineering,* vol. 26, 2019.

81 B Xiao, C Chen, and X Yin, ‘Recent advancements of robotics in construction’, *Automation in Construction,* vol. 144, 2022.

82 A Weightman, ‘Robotics adoption: Barriers and lessons from other industries’, 2022. As of 10 May 2023, https://safecrobot.pwr.edu.pl/download/d3UhJCckcxKVk6OEZhYAVTa1ATHSkoD2VbW2VFOW4ScihrEkJ-XBpxA3E4QmtQRBJdDEt7fXpISFxbYEU5UE5JRVgFXm9cAGs_ZBVMYmBbElwGV3t2dV5PRkpgXwNCf3J7WgRUMkMKfg,1qRR5WbldWfwV6GlF7XFBeEk0KHG1iAkNHXnYOQBMYAiIRWA/2_robotics_adoption_barriers_and_lessons_from_other_industries__andy.pdf

83 R Mahbub, ‘Framework on the barriers to the implementation of automation and robotics in the construction industry’, *International Journal of Innovation in Management,* vol. 3, no. 1, 2015.

84 Weightman, 2022.

85 Mahbub, 2015.

86 Weightman, 2022.

87 L Christensen et al., ‘Reviving the art of apprenticeship to unlock continuous skill development’, *The McKinsey Quarterly,* 21 October 2021.

88 Mahbub, 2015.

89 Weightman, 2022.

90 Wyatt, 2021.

91 M Yamani Bin Yahya et al., ‘The challenges of the implementation of construction robotics technologies in the construction’, paper presented at MATEC Web of Conferences: EDP Sciences, 2019.

92 A Gilli and M Gilli, ‘The diffusion of drone warfare? Industrial, organizational, and infrastructural constraints’, *Security Studies,* vol. 25, no. 1, 2016.

93 Wyatt, 2021.

94 Gilli and Gilli, 2016.

95 R Morrison, 'Compute power is becoming a bottleneck for developing AI. Here's how you clear it', *Tech Monitor,* 13 December 2022.

96 Gilli and Gilli, 2016.

97 Ibid.

98 MD Williams and PC Lawson, *Analyzing the Challenges and Obstacles to Developing and Fielding Autonomous and Semi-Autonomous Systems,* Naval Postgraduate School, 2020.

99 M Verbruggen, 'No, not that verification: Challenges posed by testing, evaluation, validation and verification of artificial intelligence in weapon systems', in T Reinhold and N Schörnig, eds, *Armament, Arms Control and Artificial Intelligence: The Janus-faced Nature of Machine Learning in the Military Realm,* Springer, 2022.

100 S Ferreira et al., 'Unmanned and autonomous systems of systems test and evaluation: challenges and opportunities', 2010.

101 Verbruggen, 2022.

102 BA Haugh, DA Sparrow and DM Tate, *The Status of Test, Evaluation, Verification, and Validation (TEV&V) of Autonomous Systems,* Institute for Defense Analyses, 2018.

103 Ibid.

104 Verbruggen, 2022.

105 Haugh, Sparrow and Tate, 2018.

106 Wyatt, 2021.

107 Ibid.

108 Williams and Lawson, 2020.

109 Interview with ROK official, April 2023.

110 PJ Durst, *The Reference Autonomous Mobility Model: A Framework for Predicting Autonomous Unmanned Ground Vehicle Performance,* Mississippi State University, 2019.

111 M Black et al., *Supporting the Royal Australian Navy's Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* RAND Corporation, 2022.

112 Ibid.

113 MC Horowitz, *AI and the Diffusion of Global Power,* Centre for International Governance Innovation, 2020.

114 Responding to this challenge is the central purpose of the newly established ASCA.

115 This refers to when a technology gets stranded in 'the space between an initial technological discovery and its adaptation into a product or capability'. See Black et al., *Supporting the Royal Australian Navy's Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022.

116 Ibid. See also L Retter et al., *Persistent Challenges in UK Defence Equipment Acquisition,* RAND Corporation, 2021; N Voss and J Ryseff, *Comparing the Organizational Cultures of the Department of Defense and Silicon Valley,* RAND Corporation, 2022, www.rand.org/pubs/research_reports/RRA1498-2.html

117 Wyatt, 2021; B Zhang et al., 'Ethics and governance of artificial intelligence: Evidence from a survey of machine learning researchers', *Journal of Artificial Intelligence Research,* vol. 71, 2021, pp. 591–666.

118 This is the 'virtual stockpile of change assets' that give the organisation the flexibility to 'respond to changes in the character of warfare'. See Horowitz, 2010.

119 Black et al., *Supporting the Royal Australian Navy's Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022.

120 MC Horowitz and S Pindyck, ‘What is a military innovation and why it matters’, *Journal of Strategic Studies,* vol. 46, no. 1, 2023.

121 Black et al., *Supporting the Royal Australian Navy’s Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022.

122 The term ‘operational praxis’ essentially refers to the process through which a military transforms capability into force, and would generally include doctrine, training and strategy. See A Grissom,, C Lee, and KP Mueller. Innovation in the United States Air Force: Evidence from Six Cases. Santa Monica, CA: Rand Corporation, 2016.

123 J Grevatt, ‘RoK Army sets up “Army Tiger Demonstration Brigade” to lead AI integration’, *Janes Defence News,* 19 August 2022.

124 Interview with ROK official, April 2023.

125 British Army, ‘Experimentation and Trials Group: Idea to operation’, *UK Ministry of Defence,* 20 June 2023.

126 Ibid.

127 Black et al., *Supporting the Royal Australian Navy’s Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022.

128 Ibid.

129 Ibid. See also J Gearson et al., ‘The whole force by design: Optimising defence to meet future challenges’, *Serco Institute,* 2020.

130 J Galliott, ‘The soldier’s tolerance for autonomous systems’, *Paladyn, Journal of Behavioral Robotics,* vol. 9, no. 1, 2018.

131 C Lee, ‘The role of culture in military innovation studies: Lessons learned from the US Air Force’s adoption of the Predator Drone, 1993–1997’, *Journal of Strategic Studies,* vol. 46, no. 1, 2023.

132 Gilli and Gilli, 2016.

133 Black et al., *Supporting the Royal Australian Navy’s Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022.

134 Ibid.

135 Ibid., p. 39. Arguably this is exacerbated by the posting cycle.

136 Rossiter, 2018.

137 Wyatt, 2021.

138 RF Laird, *Next Generation Autonomous Systems,* The Williams Foundation, 2021.

139 J Schneider and J Macdonald, ‘Looking back to look forward: Autonomous systems, military revolutions, and the importance of cost’, *Journal of Strategic Studies,* vol. 46, 2023.

140 Black et al., *Supporting the Royal Australian Navy’s Campaign Plan for Robotics and Autonomous Systems: Enhancing Innovation,* 2022, p. 14.

141 Also concerns that use of LAWS may create anti-Western sentiment in areas affected by strikes, due to the perceived indignity and unfairness of being injured or killed by an unmanned system. Interestingly, a recent article demonstrated whether racial biases shape support for drone strikes. See P Lushenko, K Carter and S Bose, ‘Do racial biases shape Americans’ support for drone strikes? We asked them’, *Modern War Institute,* 17 April 2023.

142 A Blanchard and M Taddeo, ‘Autonomous weapon systems and jus ad bellum’, *AI & Society,* 2022.

143 M Schulzke, ‘The morality of remote warfare: Against the asymmetry objection to remote weaponry’, *Political Studies,* vol. 64, no. 1, 2016.

144 JC Galliott, 'Uninhabited aerial vehicles and the asymmetry objection: A response to Strawser', *Journal of Military Ethics,* vol. 11, no. 1, 2012.

145 Galliott, 2012; Schulzke, 2016.

146 One US senior military leader summarised their position well, stating 'We're not interested in a fair fight with anyone'. See J Huggler, 'Europe faces a "real threat" from Russia, warns US army commander', *The Telegraph,* 18 April 2015.

147 YH Wong et al., *Deterrence in the age of thinking machines,* RAND Corporation, 2020.

148 Interestingly, despite the respondents' objections to the use of autonomous weapons to kill people, they were more likely to permit it if US forces were losing a battle, especially if the enemy was using autonomous weapons. FE Morgan et al., *Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World,* RAND Corporation, 2020, pp. xiv–xv.

149 I Bode and H Huelss, 'Autonomous weapons systems and changing norms in international relations', *Review of International Studies,* vol. 44, no. 3, 2018, pp. 393–413.

150 J Garamone, 'Iran shoots down US Global Hawk operating in international airspace', Department of Defense, 2019, www.defense.gov/News/News-Stories/Article/Article/1882497/iran-shoots-down-us-global-hawk-operating-in-international-airspace

151 J Crawford, 'State responsibility', in *Oxford Public International Law,* September 2006. AW Eichner, 'The limitations of system autonomy: Analyzing obstacles to the vision of autonomous horizons and the inevitable future of warfare', *Washburn Law Journal,* vol. 59, 2020.

152 A Wyatt and J Galliott, 'The revolution of autonomous systems and its implications for the arms trade', in ATH Tan, ed., *Research Handbook on the Arms Trade,* Edward Elgar Publishing, 2020.

153 Morgan et al., 2020, p. xiv.

154 RA David and P Nielsen, *Defense Science Board Summer Study on Autonomy,* Defense Science Board, 2016; Defense Science Board, *Summer Study on Autonomy,* 2016.

155 A Wyatt and J Galliott, 'An empirical examination of the impact of cross-cultural perspectives on value sensitive design for autonomous systems', *Information,* vol. 12, no. 12, 2021.

156 M Black et al., *Supporting the Royal Australian Navy's Campaign Plan for Robotics and Autonomous Systems: Human-Machine Teaming and the Future Workforce:* RAND Corporation, 2022.

157 J Macdonald and J Schneider, 'Battlefield responses to new technologies: Views from the ground on unmanned aircraft', Security Studies, vol. 28, no. 2, 2019.

158 New America, 'The War in Yemen', undated.

159 See for example the Defence Capability Manual, p. 46: 'Introduction into service occurs during the Acquisition phase, where all the relevant Fundamental Inputs to Capability comprising a capability system are delivered, integrated, tested and approved.'

160 Q Chen, B García de Soto and BT Adey, 'Construction automation: Research areas, industry concerns and suggestions for advancement', *Automation in Construction,* vol. 94, 2018.

161 RD Atkinson, 'Which nations really lead in industrial robot adoption?', *Information Technology & Innovation Foundation,* November 2018.

162 International Federation of Robotics, 'China overtakes USA in robot density', 5 December 2022. As of 22 May 2023, https://ifr.org/ifr-press-releases/news/china-overtakes-usa-in-robot-density

163 Autonomous Warrior is a RAN-led maritime exercise consisting of personnel from Australia, New Zealand, the UK and the US demonstrating various robotic, uncrewed and autonomous systems to counter future maritime security threats. This exercise was last conducted in 2022 with over 300 personnel involved and over 40 autonomous systems.

164 Defence Media, 'Exercise Autonomous Warrior testing new technologies to meet emerging maritime security challenges', Australian Department of Defence, 16 May 2022.

165 Private communications with Defence official, September 2020.

166 It is acknowledged that the Navy has now recognised this issue and has moved to develop a Fleet Warfighting Plan which is set to coordinate across all these types of activities to ensure better efficiencies and more effective outputs. Private communication with Defence official, June 2023.

167 Naval Air Systems Command, 'Quads for Squads: Marine Corps infantry receive small quadcopters', *NAVAIR,* 13 September 2017.

168 S Snow, 'Marine Corps' "Quads for Squads" has been cleared for flight', *Marine Corps Times,* 30 June 2018.

169 These group levels have been developed by the USMC to represent different sizes and costs of UAVs with inevitably different functions. They will also be present in different numbers and controlled by different force elements. For example, Group 1 and 2s will be used for fighting at platoon and company levels. Group 2 and 3s will be used for fighting at battalion and regimental levels, and within Marine Expeditionary Unit / Amphibious Ready Group constructs. Finally, the MQ-9 Reaper should be considered a Group 5 UAV, which the US Air Force will fly to perform strike missions. See M Shelbourne, 'Marines placing small UAVs into ground combat element, as aviators still refining large UAS requirement', *USNI News,* 15 September 2020.

170 D Brandes, 'Tactical Resupply Unmanned Aircraft System Demonstration', *USMC,* 11 April 2023.

171 Department of Defence, DSR, 2023, p. 71.

172 J Schogol, 'Every Marine a rifleman no more? Corps reconsidering "lateral entry" for cyber', *C4ISR Net,* 10 May 2017.

173 D Gehlhaus et al., *The DOD's Hidden Artificial Intelligence Workforce Leveraging AI Talent at the US Department of Defense,* Policy Brief, Center for Security and Emerging Technology and MITRE, September 2021.

174 C Crosby, 'Operationalizing artificial intelligence for algorithmic warfare', *Military Review,* July–August 2020.

175 Interview with Australian official, 14 April 2023.

176 Shelbourne, 2020.

177 P Dortmans et al., *Supporting the Royal Australian Navy's Strategy for Robotics and Autonomous Systems: Building an Evidence Base,* RAND Corporation, 2021.

178 While 'actor' could refer to a single decision-maker or senior leader, for the purposes of this analysis it is sufficient to abstract to the military level.

179 Horowitz, 2010.

180 Ibid.

181 Joyce, 2023.

182 See S Magnuson, 'Avalon News: Australian Air Force takes drone from "paper" to flight in two months', *National Defense,* 27 February 2023.

183 Examples of which include Fugro's remote and autonomous operations of offshore systems (see A McKie, 'Driving the remote and autonomous revolution', Fugro, 26 January 2022) and Australia's leadership in autonomous vehicles in mining operations (see S Mahmood, 'Australia leads the way in autonomous truck use', *Mining Technology,* 23 August 2021).

184 OECD, 'Gross domestic spending on R&D', 2022. As of 22 May 2023, https://data.oecd.org/rd/gross-domestic-spending-on-r-d.html

185 J Sargent, *Government Expenditures on Defense Research and Development by the United States and Other OECD Countries: Fact Sheet,* Congressional Research Service, 28 January 2020.

186 Although there is a risk that this could result in a reduction of funding directed towards lower TRL development.

187 Department of Defence, *Defence Test and Evaluation (T&E) Strategy,* Australian Government, 2021, p. 3.

188 A Dowse, 'The need for trusted autonomy in military cyber security', in H Abbass, J Scholz and DJ Reid, eds, *Foundations of Trusted Autonomy,* Springer International Publishing, 2018.

189 A Wyatt and J Galliott, 'Toward a trusted autonomous systems offset strategy: Examining the options for Australia as a middle power', Australian Army Research Centre, 2021.

190 G Ferguson, 'Preconditions for defence innovation success (Part 1): The customer's role', *ASPI Strategist,* 17 November 2017. As at 2 June 2023, www.aspistrategist.org.au/preconditions-for-defence-innovation-success-part-1-the-customers-role

191 C Deeble, DEPSEC CASG, taken from Keynote Briefing given at American Chamber of Commerce in Australia, 18 May 2023.

192 K Devitt, 'Does Australia's commitment to ethical AI give our adversaries the edge?', *WA Defence Review,* 2022, pp. 216–217.

193 M Hourihan, 'The FY 2020 Budget Request: Security R&D', *American Association for the Advancement of Science,* 2019.

194 V Boulanin and M Verbruggen, 'Mapping the development of autonomy in weapon systems', *Stockholm International Peace Research Institute,* 2017.

195 A Mehta, 'Experiment over: Pentagon's tech hub gets a vote of confidence', *Defense News,* 9 August 2018.

196 J Haner and D Garcia, 'The artificial intelligence arms race: Trends and world leaders in autonomous weapons development', *Global Policy,* vol. 10, no. 3, 2019.

197 CW Mahoney, 'United States defence contractors and the future of military operations', *Defense & Security Analysis,* vol. 36, no. 2, 2020, pp. 180–200.

198 Zhang et al., 2021.

199 T Brewster, 'Project Maven: Startups backed by Google, Peter Thiel, Eric Schmidt and James Murdoch are building AI and facial recognition surveillance tools for the Pentagon', *Forbes,* 8 September 2021. As of 2 June 2023, www.forbes.com/sites/thomasbrewster/2021/09/08/project-maven-startups-backed-by-google-peter-thiel-eric-schmidt-and-james-murdoch-build-ai-and-facial-recognition-surveillance-for-the-defense-department/?sh=11226b6c6ef2

200 See for example FP Explainers, 'Explained: The debate in the United States over regulating AI', 16 May 2023, *Firstpost*. As of 2 June 2023, www.firstpost.com/explainers/explained-the-debate-in-the-united-states-over-regulating-ai-12601832.html

201 Devitt, 2022.

202 Office of the Under Secretary of Defense for Policy, ‘DoD Directive 3000.09: Autonomy in Weapon Systems’, US Department of Defence, 25 January 2023.

203 PS Pramudia, ‘China’s strategic ambiguity on the issue of autonomous weapons systems’, *Global: Jurnal Politik Internasional,* vol. 24, no. 1, 2022, pp. 1–34.

204 Bode et al., 2023.

205 EB Kania, ‘Chinese military innovation in artificial intelligence’, testimony to the US-China Economic and Security Review Commission, 2019.

206 Wyatt, 2020.

207 Haner and Garcia, 2019.

208 G Allison, *Destined for War: Can America and China Escape Thucydides’s Trap?,* HarperCollins, 2017, cited in Wyatt, 2020.

209 Kania, 2019.

210 Ibid.

211 LY Hunter et al., ‘The military application of artificial intelligence technology in the United States, China, and Russia and the implications for global security’, *Defense & Security Analysis,* 2023.

212 Wyatt, 2020.

213 Kania, 2019.

214 Wyatt, 2021; Bode et al., 2023.

215 A Wahal, ‘On international treaties, the United States refuses to play ball’, *Council on Foreign Relations,* 7 January 2022, www.cfr.org/blog/international-treaties-united-states-refuses-play-ball

216 Ministry of National Defense, ‘Defence Innovation 4.0’, Republic of Korea, undated.

217 L Hunter et al., ‘A lesser-known arms race: The military application of artificial intelligence in non-major power developed states and the implications for global security’, *International Journal of Security Studies & Practice,* vol. 3, no. 1, 2023.

218 For example, the collaboration between KAIST and Hanwha. See Hunter et al., ‘A lesser-known arms race’, 2023.

219 Haner and Garcia, 2019.

220 Hunter et al., ‘A lesser-known arms race’, 2023.

221 Interview with ROK official, April 2023.

222 Ibid.

223 Boulanin, 2016.

224 Scharre, 2018.

225 J Reed, ‘Israel’s killer robot cars’, *Foreign Policy,* 20 November 2012.

226 Scharre, 2018.

227 HM Roff, ‘The strategic robot problem: Lethal autonomous weapons in war’, *Journal of Military Ethics,* vol. 13, no. 3, 2014.

228 DD Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel,* Stanford University Press, 2010.

229 RA Bitzinger, ‘Military-technological innovation in small states: The cases of Israel and Singapore’, *Journal of Strategic Studies,* vol. 44, no. 6, 2021.

230 Bitzinger, 2021.

231 M Baruch et al., *Final Report—Robotics and Autonomous Systems,* National Defense Strategy, 2015.

232 Bitzinger, 2021.

233 Ibid.

234 RD Marcus, 'Learning "under fire": Israel's improvised military adaptation to Hamas tunnel warfare', *Journal of Strategic Studies,* vol. 42, no. 3–4, 2019, pp. 344–370.

235 M Raska, *Military Innovation in Small States: Creating a Reverse Asymmetry,* Routledge, 2015.

236 Bitzinger, 2021.

237 Bode and Huelss, 2018.

238 UK Ministry of Defence, 'Joint Doctrine Publication 0-30.2. Unmanned Aircraft Systems', 2017, p. 72.

239 Bode and Huelss, 2018.

240 Boulanin, 2016.

241 Hunter et al., 'A lesser-known arms race', 2023.

242 These include Defence AI and Autonomy Unit, an AI Lab within Dstl, the JHub program, Project Nelson and the Centre for Artificial Intelligence.

243 DASA is a UK Government initiative across all fields of science and technology that funds 'better ways of working, better services, or any innovation that will make defence and security more effective'. See GOV.UK, DASA, 'About us', undated.

244 Wyatt, 2021.

245 UK Ministry of Defence, 'Ambitious, safe, responsible: Our approach to the delivery of AI-enabled capability in Defence', 2022.

246 Wyatt, 2021.

247 Ibid.

248 Raska, 2015.

249 Wyatt, 2021.

250 This table was created by Jonathan Wong, Associate Director of the Strategy, Doctrine, and Resources Program of the RAND Arroyo Center, using material presented in this report.

researchcentre.army.gov.au

CG DEC009-23