HCSS Security

The Military Applicability of Robotic and Autonomous Systems

Bianca Torossian, Frank Bekkers, Tim Sweijs, Michel Roelen, Alen Hristov and Salma Atalla.

Contents

1 Introduction

1.1 This document

This paper assesses the military utility of robotic and autonomous systems (RAS) and the risks and opportunities associated with the development and use of this technology in a military context. For the purposes of this paper, the time horizon is set at five to ten years into the future and the scope of the military application areas pertains to land operations performed by the Royal Netherlands Army (RNLA).[1]

This paper is organized according to the following structure. In this chapter, we offer our demarcation of RAS, which lacks an internationally accepted definition; give a classification of distinct levels of autonomy of RAS solutions in a military context; and present a taxonomy of military functions for which RAS solutions may be deployed. Chapter 2 presents a classification of RAS in a military context as the basis for a structured discussion. Chapter 3 is dedicated to the evaluation criteria that may be used to assess the military utility of RAS solutions. In Chapter 4, based upon an extensive dataset, we map current RAS and RAS under development on the taxonomy of military functions provided in Chapter 2, in order to gain a feel for the current military applicability of RAS. In this chapter, we further hypothesize which future systems will be available in the coming five to ten years. Chapter 5 outlines the main risks and opportunities associated with the development and military use of this technology from practical and societal perspectives. Chapter 6 concludes by setting out the necessary steps required for the successful implementation of RAS in the military.

1.2 Approach

The content of this paper is derived from two complementary and interacting approaches. The first approach comprises an extensive review of the relevant literature. From this literature review, our classification of RAS in a military context and our list of evaluation criteria for the military utility of RAS were derived. This overview was largely based on *The SIPRI Dataset of Autonomy in Weapons Systems*[2] with some minor adjustments.[3] The SIPRI dataset was further refined, categorized according to our taxonomy of military functions, and augmented with additional systems from other sources, resulting in a dataset comprising of 299 systems.[4]

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[1] Embedded, as it is, in the Netherlands Armed Forces, in international cooperation frameworks and in the Dutch 'security ecosystem'.
[2] Boulanin and Verbruggem, "Mapping the Development of Autonomy in Weapon Systems."
[3] Our overview also made use of systems identified in the British Army Innovation Technology Book (BAITB), as well as studies conducted by the U.S. Congressional Research Service, Zhifeng Lim, and Boulanin & Verbruggen. "Army Warfighting Experiment 2018: Autonomous Warrior"; Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI)*; Boulanin and Verbruggem, "Mapping the Development of Autonomy in Weapon Systems"; Lim, "The Rise of Robots and the Implications for Military Organizations."
[4] It is important to note the limitations that affect the process of open source data collection. It can be assumed that countries may classify information on RAS and RAS developments for national security purposes. Therefore, while the majority of RAS are categorized under 'Information and Intelligence', while 'Use of Force' has the least RAS

The second approach was focused on acquiring the expertise and experience of practitioners, researchers, legal specialists, ethicists and members of the defense community. This practical approach manifested in a workshop attended by 55 experts from industry, the defense community, academic and research institutes and the wider unmanned systems community.[5] The following questions were posed to the workshop participants (working in six separate groups):

1. What is the military utility of **RAS for different military functions** (Service & Support, Information & Intelligence, Use of Force), both in themselves and/or to augment or substitute more human centric solutions? What level of autonomy is feasible or required (possibly a growth path)?
2. What are the **technical, organizational and doctrinal - i.e. practical - issues and challenges** in the actual implementation of the suggested (high-utility) RAS solutions? What are critical steps/actions to be taken (now) in order to deal with these issues and challenges?
3. What are the **ethical, legal and societal - i.e. conditional - issues and challenges** in the actual implementation of the suggested (high-utility) RAS solutions? What are critical steps/actions to be taken (now) in order to deal with these issues and challenges?

The insights of the participants were noted and analyzed, and have primarily contributed to section 4.2 (future military applications of RAS) and chapters 5 (opportunities and risks) and 6 (next steps). The workshop was also instrumental in gauging the framework in the chapters 2 and 3.

2 Categorization of RAS in a military context

2.1 Demarcation of RAS

There is no single internationally accepted definition of RAS. However, for the purposes of this paper, the following definitions describe the concepts most accurately.[6]

Autonomy: The level of independence that humans grant a system to execute a given task. It is the condition or quality of being self-governing to achieve an assigned task based on the system's own situational awareness (integrated sensing, perceiving, analyzing), planning, and decision making. Autonomy refers to a spectrum of automation in which independent decision making can be tailored for a specific mission, level of risk, and degree of human-machine teaming.

solutions, it may be that the actual amount of RAS for Use of Force is broader than what is known due to the classified status of projects.

[5] The expert workshop was held at The Unmanned Systems (TUS) Expo in Rotterdam on the 18th of January 2019. The participants were split into five focus groups, each of which were lead by a member of the HCSS project team.

[6] The following definitions are taken from Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI)*.

Robot: A powered machine capable of executing a set of actions by direct human control, computer control, or both. It is composed minimally of a platform, software, and a power source.

Robotic and Autonomous Systems (RAS): RAS is an accepted term in academia and the science and technology (S&T) community and highlights the physical (robotic) and cognitive (autonomous) aspects of these systems. RAS is a framework to describe systems with both a robotic element and an autonomous element.

It is important to note that each of the consecutive parts of RAS covers a broad spectrum. The 'systems'-part refers to a wide variety of physical systems over a wide range of (in our case: military) application areas. Automated software systems running on computers or networks, including 'bots', pieces of software that can execute commands with no human intervention, do not qualify as RAS because they lack a physical component. The 'robotic' part, which refers to the physical layout of the system, holds that the system is unmanned or uninhabited. All other physical aspects (size, form, whether it flies, floats or rolls, etc.) are left open. The 'autonomous' part, which refers to the cognitive design of the system, covers the full range from fully controlled by a remote human operator to fully controlled by internal logic, i.e. the 'program' or 'software' that determines the system's behavior. In a military context, it is important to distinguish the overarching category of RAS from the much smaller category of lethal autonomous weapons systems (LAWS). Only a small fraction of the full scope of military RAS involve LAWS. Again, there is no agreed definition. The following description is the 'working definition' that the Netherlands put forward in the ongoing debate on autonomous weapon systems that takes place within the Convention on Certain Conventional Weapons (CCW):

Lethal Autonomous Weapon System (LAWS): A weapon that, without human intervention, selects and engages targets matching certain predefined criteria, following a human decision to deploy the weapon on the understanding that an attack, once launched, cannot be stopped by human intervention.

2.2 Levels of autonomy

The 'autonomous' part of RAS is the most discussed and most constrained. A crucial notion is **meaningful human control** (MHC). The formal Dutch standpoint is that "all weapons, including autonomous weapons, must remain under meaningful human control." Again, there is no internationally accepted definition. MHC encompasses (at least) the following three elements:[7]

- People make informed, conscious decisions concerning the use of weapons;

[7] Horowitz and Scharre, "Meaningful Human Control in Weapon Systems," 4 This definition (in Dutch translation) is also used in the AIV/CAVV report, Autonome wapensystemen. De noodzaak van betekenisvolle menselijke controle, from October 2015.

- People are adequately informed in order to ensure that the use of force conforms to international law, within the scope of the knowledge that they have on the goal, the weapon, and the context in which the weapon is put to use;
- The weapon in question has been designed and tested in a realistic operational setting and the people involved have received adequate training, in order to use the weapon in a responsible manner.

Yet, MHC is a complex concept and in many cases the above description is not conclusive. Likewise, the often used distinction between human-in-the-loop, human-on-the-loop and human-out-of-the-loop does not suffice. These terms refer to the relationship between an unspecified human and an unspecified decision loop, whereas in reality a number of different humans may relate to a number of different loops. Many of these loops are non-operational, e.g. play out in the design phase of RAS. Also, these terms cover the aspect of human control (or machine freedom). Two other concepts also embedded in the term autonomy are the complexity of the machine and the type of decision being automated.

For our purposes, we propose a taxonomy (see *Table 1*) based on the SAE international standard J3016, which identifies six levels of driving automation to categorize self-driving cars.[8] We have slightly adapted that standard to fit our context of military use. The column labelled 'monitoring the environment' specifies whether a human operator must monitor the environment in which the machine performs its task in order to decide 'the next step' at crucial decision points; or to overwrite the automated logic if something goes wrong. The column labelled 'fall-back performance' indicates what happens when unexpected situations arise: does the operator or the automated system decides how to (re)act? The 'task performance modes' column indicates whether for certain functional aspects the level of autonomy can be switched back in order to increase human involvement.

[8] SAE International, "Automated Driving: Levels of Driving Automation Are Defined in New SAE International Standard J3016."

Table 1: Levels of Autonomy

Level of autonomy	Description	Execution of core task	Monitoring environment	Fall-back performance	Performance modes
0: Remotely Controlled	the full-time performance by the operator of all aspects of the dynamic core task,[9] even when enhanced by warning or intervention systems	operator	operator	operator	n/a
1: Operator Assistance	the mode-specific execution by an assistance system of certain functional aspects[10] of the core task, using information about the environment, while the operator performs all remaining aspects of the core task, and with the expectation that the operator will respond appropriately to a request to intervene	operator / system	operator	operator	some modes
2: Partial Automation	the mode-specific execution by an assistance system of all functional aspects of the core task, using information about the environment, and with the expectation that the operator will respond appropriately to a request to intervene	system	operator	operator	some modes
3: Conditional Automation	the mode-specific execution by one or more assistance systems of all functional aspects of the core task, using information about the environment, and with the expectation that the operator will respond appropriately to a request to intervene or/and can override the autonomous behavior	system	system	operator	some modes
4: High Automation	the mode-specific execution by one or more assistance systems of all functional aspects of the core task, using information about the environment, even if the operator does not respond appropriately to a request to intervene	system	system	system	some modes

[9] The dynamic core task of a RAS is the task performed in direct connection to the mission the RAS was set to do. For military applications, these various tasks can be derived from the categorization above. For a cargo drone, for instance, this core task would be navigating safely to a drop-of location, delivering the cargo intact, and return home. For a surveillance drone this would be to spot and track moving targets that fit certain characteristics.

[10] It is assumed that a core task can be broken down in functional aspects in a modular fashion. E.g. for the cargo drone the core task would consist of a navigation part (to reach the drop-of location; as well as return home) and a drop-of part (deliver the cargo).

Table 1: Levels of Autonomy (continued)

Level of autonomy	Description	Execution of core task	Monitoring environment	Fall-back performance	Performance modes
5: Full Automation	the full-time performance by an automated system of all aspects of the core task under all environmental conditions to at least the same level as can be managed by an operator	system	system	system	all modes

A further subcategorization for levels four and five to distinguish between levels of MHC is conceivable. An example might be the presence or lack of an 'override switch' that allows a human operator to abort the automated mission. Another issue could be the extent in which the system is able explain its reasoning in deciding on a particular course of action (in advance, in real time or afterwards). This form of transparency is important for evaluation and possibly correction of the autonomous logic.

2.3 Taxonomy of military functions for RAS deployment

We propose a three tier taxonomy of military functions that may be performed using RAS-solutions, facilitating discussions at various levels of abstraction/granularity (*Figure 1*). The first level consists of four broad categories. The categories at the second level are listed alphabetically. These two levels are comprehensive, i.e. intended to cover the full range of all possible military applications of RAS that we might think of as fitting under one or more of the level 1 and level 2 categories. At the third level, the categorization is not fixed. At that level of detail, a great number of detailed military functions for RAS may arise, including possible new ones that have currently no 'manned' equivalent (because it is too dirty, dull and/or dangerous for humans to perform). The subcategories at level 3 given below are to be considered as representative examples.

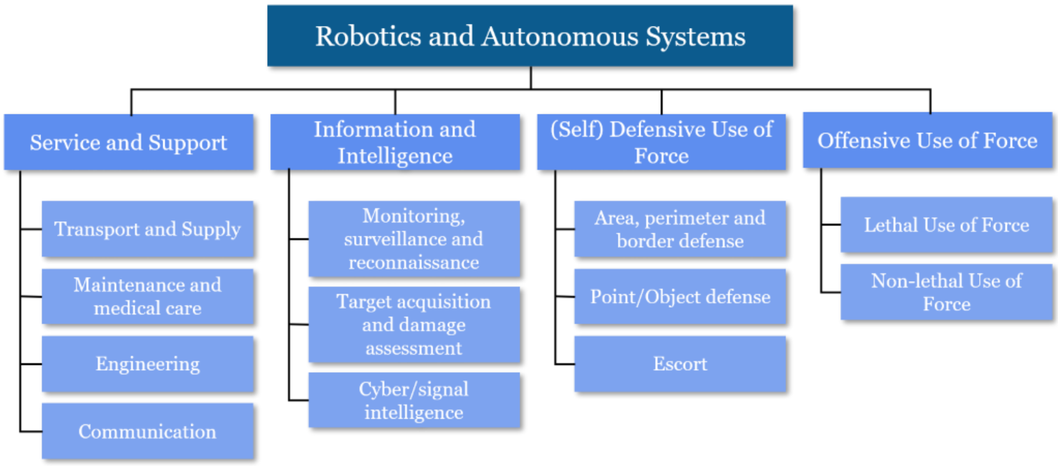

Figure 1: HCSS Taxonomy of military functions for RAS (Level 1 &2)

1. RAS applied in **Service & Support** activities is roughly equivalent to what the military call 'combat service support'. The execution of these activities typically resides in non-combat units. Indeed, most of these activities have non-military equivalents, with dual-use systems being feasible. For this main category, technological developments, as well as issues regarding rules and regulations and certification, are largely driven by civil sector applications. This implies that future military RAS applications in this functional category tend to be inspired by, and make extensive use of, civil innovations. This category comprises the following level 2 functions:

    a. **Transport & Supply** includes transport and salvage & recovery of materiel; transport, search and rescue and (medical) evacuation of personnel; storage and distribution of supplies (e.g. aerial refueling); trash collection and recycling; and navigation support. In geographical terms, transport & supply is to and from theatres of operation as well as within those theatres.

    b. **Maintenance / Medical Care** is particularly aimed at actual operations. Outside of operations, this function typically merges with non-military (general) maintenance and medical care functions.

    c. **Engineering** includes construction and demolition; mobility and counter-mobility measures; and clearance of mines, IEDs and explosives (Explosive ordnance disposal, EOD).

    d. **Communication** includes all activities in support of creating or supporting one's own facilities for communication. E.g. mobile radio repeaters.

2. RAS applied in **Information & Intelligence** activities for the gathering (sensing) and processing of information in support of military planning, situation awareness & situation understanding (SA/SU) and decision making. Many of these activities have non-military equivalents, with dual-use systems feasible. However, military applications often represent a specific high-end niche, with advanced technological developments still largely set by military uses. This category comprises the following level 2 functions:

    a. **Monitoring, surveillance and reconnaissance** includes observing the wider sea-land-air/space environment for potential threats, incidents, security breaches etc.

   b. **Target acquisition and battle damage assessment** is distinct from the previous one, in the sense that its focuses on designated targets.

   c. **Cyber/signal intelligence** pertains to information gathering and intelligence production in the electronic domain, both in the digital / cyber infrastructure and in the electromagnetic spectrum.

3. RAS applied in **(Self) Defensive Use of Force**. This category includes the use of force in response to a clear and present danger to the system itself or to a defended asset or area. This response is typically aimed at incapacitating the incoming threat, such as a missile or a projectile. This category has limited equivalents in civil security. Technological developments, as well as issues regarding rules and regulations and certification, are therefore largely driven by military applications. This category comprises the following level 2 functions:

   a. **Area / perimeter / border defense** pertains to a geographically extended defense.

   b. **Point / object defense** of a single object such as a building or a confined military position, as well as self-defense of the system itself.

   c. **Escort** pertains to the defense of moving objects such as convoys.

4. RAS applied in **Offensive Use of Force**. This category pertains to the use of force with the explicit aim to deliberately incapacitate or kill people or deliberately damage or destroy objects (without necessarily being provoked). This category has no or little non-military equivalents. Technological developments, as well as ethical and legal issues, are therefore almost exclusively driven by military uses. This category comprises the following level 2 functions:

   a. **Lethal use of force** with the intention to kill or destroy the target.

   b. **Non-lethal or less-lethal use of force** with the explicit intention to (temporary) incapacitate the target.

3 Assessing the military value of RAS

In order to gauge the added value of RAS to the RNLA, it is necessary to identify the different ways in which these systems can (or cannot) positively contribute to the capabilities of the organization. This safeguards against innovation for innovation's sake and frames the development of RAS in terms of its potential to produce tangible, perceivable outcomes for the RNLA. In order to determine the military utility of RAS to the RNLA, we propose the following criteria (see *Figure 2*):

1. **Effectiveness** to achieve the desired effect(s) or objective(s) for the military task(s) / mission(s) where RAS is deployed.
2. **Efficiency** in the use of resources. Ideally, both the life cycle costs of the system (initial investment, maintenance, upgrades, etc.) as well as running costs (e.g. for fuel, spare parts and repair) are taken into account.
3. **Agility** to adapt according to the requirements of the situation at hand, and also to adapt over time to new situations.

4. **Legitimacy** of the application of RAS, both in a formal sense and as perceived by the (military) operators and by the people/societies, in theatre as well as at home.

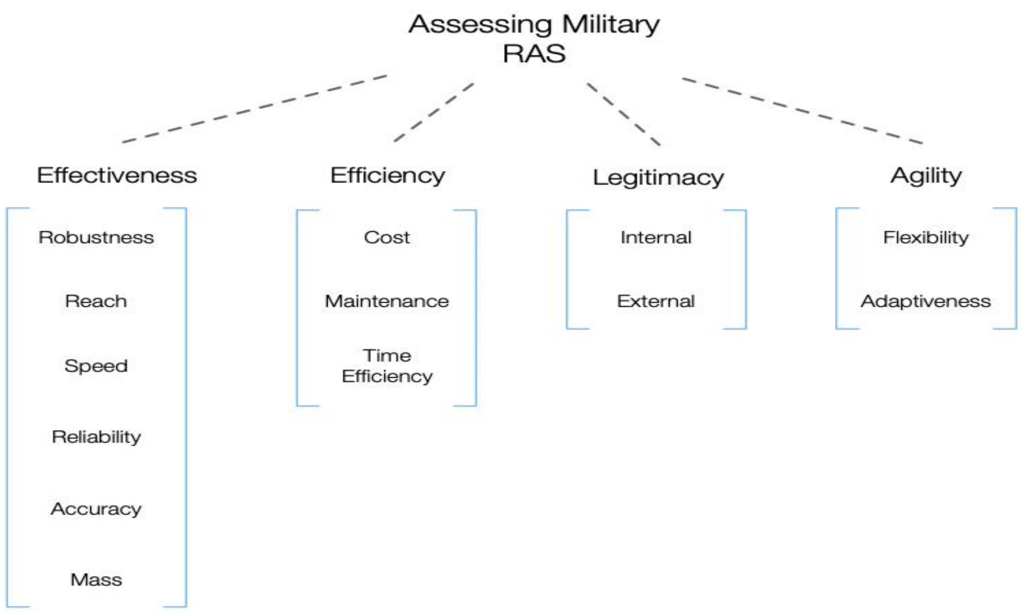

Figure 2: Evaluation Metrics used to Assess RAS

Each criterion is further broken down into sub-criteria that seek to measure whether and how RAS solutions generate added value for the military. Given the variety of military functions to consider, it is impossible to give generic absolute levels of performance for each of these criteria. What *is* possible, is for concrete applications to gauge the (expected) *relative* performance of proposed RAS solutions against current human-centric / manned solutions.

3.1 Effectiveness

Speed. Rapid action and the element of surprise are integral to defy counter measures and supersede adversaries. Improvements to reaction times, speed in decision-making and rapid mobility and deployment across land, air and sea would invaluably enhance the strategic position of the RNLA.[11] With the help of artificial intelligence, which stimulates rapid decision-making and prioritization of threats, RAS are already capable of surpassing human reaction times and shortening the OODA (Observe, Orient, Decide, Act) loop.[12]

Speed is also an important metric of evaluation when considering 'Search and Support' roles of RAS, particularly maneuverability across conflict spaces. With logistical support from RAS, operatives can move to, from and around conflict spaces at greater ease, with less physical load and subsequently, at a faster pace.

[11] UK Ministry of Defence, "Joint Concept Note 1/18," 13.
[12] Reilly, "Beyond Video Games."

Reliability. Delegating tasks to machines requires an immense degree of trust, especially considering the critical situations that the military is designed to thrive in. A key element of this trust is reliability, i.e. *has this function consistently worked effectively in previous circumstances?* When given critical situation, command would choose a human operative they could rely on over a machine that could do the job better - but only sometimes. At present, RAS are yet to prove adequate reliability across all military application areas. However, just as we trust a GPS over our own senses of navigation, so too will our confidence in other technological systems increase as they prove their reliability and effectiveness in executing specific tasks.

Accuracy. Accuracy is particularly contentious when it comes to strike capabilities as militaries seek to diminish the collateral damage of conflict and adhere to international standards on the protection of civilians. One of the main arguments in favor of unmanned aircraft strike (drone) missions, is that it is more precise. However, while AI systems have developed facial image recognition and sensory abilities past the level of human performance, the claim that unmanned systems are more precise than human operatives is widely disputed. A 2016 study disproved the claim that unmanned drones are more 'precise' and cause fewer civilian fatalities than airstrikes by manned aircrafts.[13] In fact, the research found that drone strikes are approximately thirty times more likely to result in a civilian fatality than an airstrike by a manned aircraft.[14]

Mass. Owing to increased range and endurance, RAS has the capability to enhance coverage of the battlespace and overwhelm adversaries. The best example of this potential is swarming, whereby a large quantity of physical, multi-robot systems use AI and advanced network communication to conduct highly-coordinated operations. With this coordination and smart mass, swarms are able to apply sustained pressure and use the frenzy of a simultaneous offensive to overwhelm adversaries. Additionally, whereas traditional mass involving concentrated force is problematic in terms of coordination and concealment, and dispersed systems are vulnerable to deficiencies in command and control, RAS have the potential to combine firepower, coordinated control and maneuverability.[15] Therefore, small systems but with superior AI will have the ability to defeat systems that use more traditional force. The risk here is that if communication between the multiple robotic systems is cut off (i.e. due to signal jamming), an affront ceases to be a concentrated and concerted effort, and is subsequently rendered futile. However, with continued advancements in military technology (including the resilience of device-to-device communication systems) it is plausible to see a shift from greater physical mass towards smart mass.

[13] Wolf and Zenko, "Drones Kill More Civilians Than Pilots Do."
[14] Wolf and Zenko.
[15] UK Ministry of Defence, "Joint Concept Note 1/18," 34.

Reach. Similar to mass, extending reach is highly dependent on the ability of cells within the system to communicate and coordinate. When compared to human combatants, RAS greatly enhance the available points of presence for surveillance, intelligence, reconnaissance and weapons systems. This pertains not merely to the scope of the physical battlespace, but also to the use of RAS in cyber operations.[16] Furthermore, the use of RAS for Service and Support can extend the reach of human operatives on the ground by prolonging the moment whereby fatigue, diminishing supplies and transport maintenance restrict the length of a mission.

Robustness. The quality of being strong and/or unlikely to break or fail, especially during unexpected circumstances and against shocks, is particularly important given the hazardous nature of the operational environment. The development and implementation of quality assurance standards and certification processes will be critical in this regard. At least in the short term, RAS will be more vulnerable than humans to fail due to a small detail or an unanticipated change to the mission. This frailty extends beyond the physical domain towards the virtual domain, as losses in connection (for example through signal jamming), hacking and other interference can render a system incapable.

Safety. A distinct advantage of the integration of RAS into military functions is their ability to perform 'dull, dangerous and dirty' tasks. This leaves humans to focus on the more specialized tasks instead of those which are repetitious and messy, and most importantly, to be kept out of the line of fire. Although it is undeniable that remote controlled robots are saving the lives of soldiers, the strong emotional bond that humans form with their robotic team members can, in exceptional circumstances, have a paradoxical effect as soldiers have been known to risk their lives to save robots.[17] Aside from this, as advancements in robotic systems and human-machine teaming continue, and the technology gains trust through reliability, their use in more dangerous missions will intensify and we can subsequently expect a greater degree of safety for troops.

3.2 Efficiency

Cost. Efficient use of RAS has potential to substantially increase the cost effectiveness of defense processes.[18] Currently, the cost associated with pioneering and/or obtaining the latest RAS means that the development of this technology has been undertaken by a relatively small group of actors. However, as developers learn to adapt the technology in commercially available systems (such as smartphones), capabilities such as image recognition, navigation and remote operation, will become far less costly to acquire. Although exclusive access to the most cutting-edge

[16] UK Ministry of Defence, vi.
[17] Hsu, "Real Soldiers Love Their Robot Brethren."
[18] UK Ministry of Defence, "Joint Concept Note 1/18," 7.

technology will be reserved for the wealthiest players, the cost of systems that are now considered highly-advanced will fall throughout the next twenty years, thus becoming more widely attainable.[19] The degree to which RAS technologies are cost effective is also highly dependent on other evaluation metrics, such as whether the system is agile and applicable to multiple scenarios.

Maintenance. As with any technology, RAS require software and hardware upgrades in order to sustain accelerated capability development. Maintenance may also come in the form of fixing existing systems. While this metric is especially difficult to evaluate for RAS in general, it is nonetheless an important factor to consider when developing, purchasing or introducing RAS into a context.

Time efficiency. The performance of RAS in regard to time efficiency is one of the strongest arguments in support of its deeper and more widespread integration into militaries. RAS can perform dull and repetitive monitoring tasks at a high standard 24/7 without the need for rest, logistical planning can be solved efficiently, and the limits of human multitasking can be quickly surpassed.[20] This efficiency also allows for fast deployment and the reconfiguration of plans *en route*.[21]

3.3 Agility

Flexibility. Flexibility refers to the ability to change or be changed easily according to the situation. A flexible system can take on a variety of missions and/or perform these missions under a wide range of circumstances (e.g. climate, weather and terrain). Although RAS currently excel in executing specific tasks and humans will remain the most flexible for the foreseeable future. This dynamic is likely to change as developers continue to innovate current systems. Presently, RAS extend the current flexibility of humans through human-machine teaming. An example of this is a service and support drone that can transcend the limits of a human team's ability to surveil in harsh environments, such as deserts. Thus, when the mission encounters (unexpected) challenges, RAS have the capability to make the team more flexible.

Adaptiveness. By contrast, adaptiveness indicates how a system may be changed over time or according to new circumstances. Where flexibility pertains to the versatility of the system as-is (i.e. during a mission), adaptiveness considers the potential of the system to be easily reconfigured (scaled, extended, upgraded etc.) over time so to keep up with new requirements emerging in a dynamic environment (i.e. during the system's life cycle).

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[19] UK Ministry of Defence, 5.
[20] UK Ministry of Defence, 44.
[21] U.S. Army, "The U.S. Army Robotic and Autonomous Systems Strategy," 10.

3.4 Legitimacy

External. Legitimate use of RAS encapsulates compliance with the Dutch Constitution, international law (including Laws of War) and national legislation. Acting in accordance with the law becomes more contentious with higher degrees of autonomy and lethality of RAS, as discussed earlier. The establishment of certification regimes and clarification on precisely how (international) law applies to the development of RAS is instrumental in evaluating legitimacy in this regard. Additionally, as the army seeks to be engaged in society and inherently reflects the values of the society it serves, it must act within the parameters of societal acceptability. While these parameters are fluid and illusive in a continuously evolving society, positive public opinion (or at least passive acceptance) is of great importance to the army. As a socially responsible organization, RNLA's engagement with RAS must thus strike a balance between the advanced capabilities they (potentially) provide and the values and norms of the society it serves.

Internal. As operators of RAS, the RNLA must also be willing to implement RAS into their operations. This willingness is not only dependent on the external legitimacy of the system (legality, certification and ethics), but also on the degree to which the system is trusted to execute a task.[22] Trust and organizational normalization of RAS will be strengthened over time as understanding of the systems, their predictability and their familiarity are enhanced.[23]

4 Current RAS applications in the land domain

4.1 Overview of current systems

The dataset of RAS used by HCSS largely builds upon a SIPRI dataset which encompasses over 380 RAS classified into a number of general categories.[24] Our overview currently comprises 299 distinct RAS solutions. The majority of RAS are categorized under **Information and Intelligence**, while **Use of Force** has the least RAS solutions. It might be that the actual amount of RAS for **Use of Force** is broader than what can be asserted, precisely because of limitations due to the classification of matters concerning national security. Furthermore, collecting data on RAS in

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[22] UK Ministry of Defence, "Joint Concept Note 1/18," 48.
[23] UK Ministry of Defence, 48.
[24] Despite the comprehensiveness of the SIPRI list, it contains several limitations, in particular with regards to its generic classification of RAS based on their purpose, i.e. their function. The SIPRI dataset ranges from systems that are operational, under development and cancelled/retired. For our purposes, the systems which are either retired or cancelled were excluded, along with the systems employed in the maritime domain. Our overview also made use of systems identified in the British Army Innovation Technology Book (BAITB), as well as studies conducted by the U.S. Congressional Research Service, Zhifeng Lim, and Boulanin & Verbruggen. The resulting dataset used by HCSS is for some 90% based on the SIPRI dataset, for 4-5% on the British Army Technology book, and for 5-6% on the additional studies. The data presented in this paper is accurate as of time of writing: March 2019. "Army Warfighting Experiment 2018: Autonomous Warrior"; Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI)*; Lim, "The Rise of Robots and the Implications for Military Organizations"; Boulanin and Verbruggem, "Mapping the Development of Autonomy in Weapon Systems."

countries such as China and Russia is restricted by their known secrecy as well as language barriers.

In this part, a factual overview of current RAS is depicted, using the HCSS taxonomy of military functions (see *Figure 1*). The section will proceed by firstly demonstrating the first tier of this taxonomy; and then by the second tier, which offers a more detailed account of potential military applications of RAS. In furtherance of providing a clear broad view of RAS production and use, visualizations will display the approximate number of projects produced/ employed per country.

We categorized 299 RAS on the basis of their military functions, namely in the domains of **Service & Support**, **Information & Intelligence**, **Defensive Use of Force** and **Offensive Use of Force**, forming the first level of categorization. *Figure 3,* portrays the second tier of RAS, offering a more comprehensive view on HCSS' taxonomy of the systems.

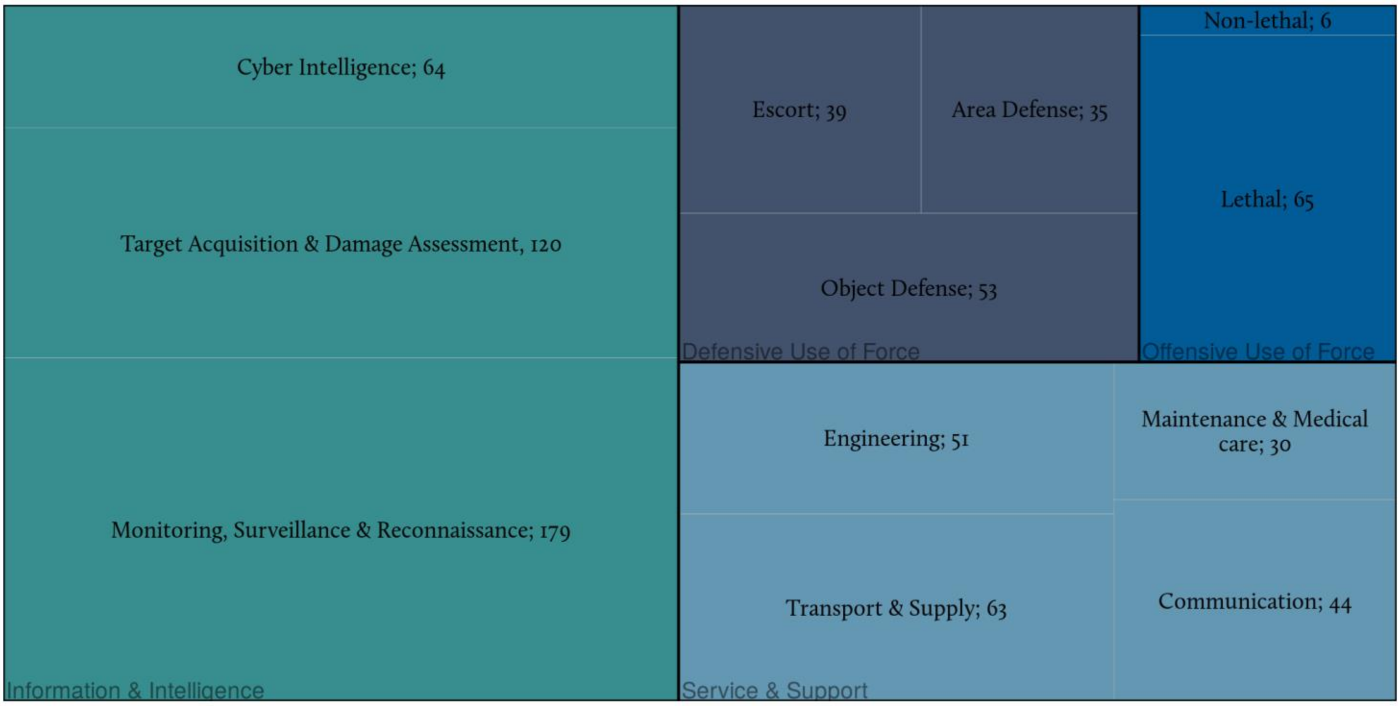

Figure 3: represents Tier 2 of The HCSS RAS Taxonomy

As exhibited below in *Figure 4,* the majority of RAS are used for **Information and Intelligence** gathering purposes, with a total of 224 Systems, including *Hermes 900*[25] and *Nerva.*[26] The second most prevalent domain is **Service and Support**,

[25] *Hermes 900* is an unmanned air vehicle (UAV) system that is used by the Israeli Defense Force for operations requiring intelligence, surveillance, target acquisition and reconnaissance (ISTAR).

encompassing 126 RAS, such as the *Amulet UAS*[27] and *Guardium-LS.*[28] In regards to use of force, 85 RAS were labeled under **Defensive**, with systems alike *Otomatic*[29] and the *Norwegian Advanced Surface-to-Air Missile System (NASAMS).*[30] Lastly, 69 systems were recognized as **Offensive**, and those include *Skystriker.*[31]

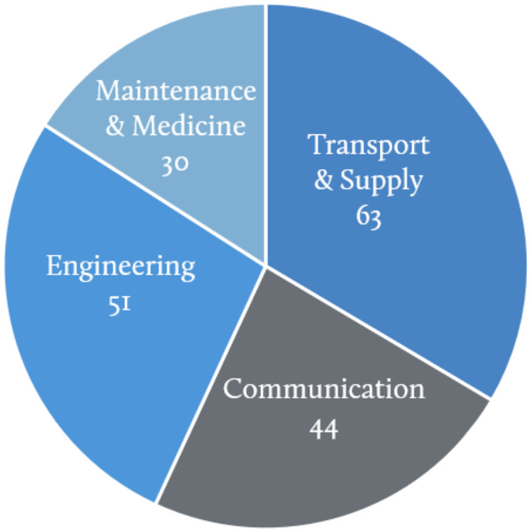

Figure 4: Categorization of Tier 1

Information & Intelligence. This category is branched into **Monitoring, Surveillance and Reconnaissance (MS&R)**, **Target Acquisition and Battle Damage Assessment (TA&BDA)** and **Cyber Intelligence**. *Figure 5* pinpoints MS&R as the largest sector with 179 RAS, TA&BDA is consequent at 120 systems, and finally, 64 under Cyber Intelligence.

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[26] *Nerva* is a 2-wheel compact robotic platform, equipped with high-definition and thermal camera to serve its reconnaissance purpose.
[27] The *Amulet* is an unmanned air system (UAS) that is able to detect buried landlines, improvized explosive devices (IEDs) and emplaced explosive ordnance from a standoff distance.
[28] Guardium-LS is a multi-purpose autonomous unmanned ground vehicle that is able to provide troops with 1.2 tons worth of ammunition and supplies without endangering manned vehicles over routes stricken with IEDs.
[29] *Otomatic* is an armored anti-aircraft vehicle with the ability to detect enemy stealth aircraft.
[30] *NASAMS* s a medium to long range air defense missile system. It can recognize, engage and destroy helicopters, aircraft, cruise missiles and UAVs, and protects against air-to-surface threats.
[31] *Skystriker* is a Loitering Munition (LM) designed for use by the tactical level corps. The LM is able to seek, target and engage various targets.

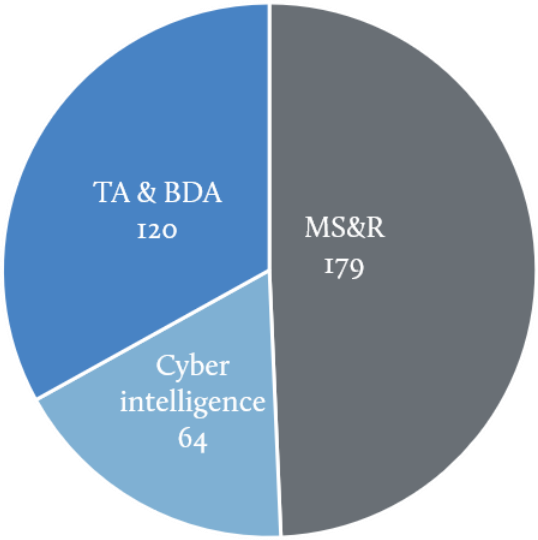

Figure 5: Information and Intelligence Systems

Service and Support. *Figure 6* exhibits the **Service and Support** category with its four sectors, namely **Transport and Supply**; **Engineering**; **Communication** and lastly, **Maintenance and Medicine.** As the pie chart shows, the Transport and Supply sector is leading with 63 systems, followed by Communication at 44, Engineering at 51 and lastly Maintenance and Medicine covering a mere 30**.**

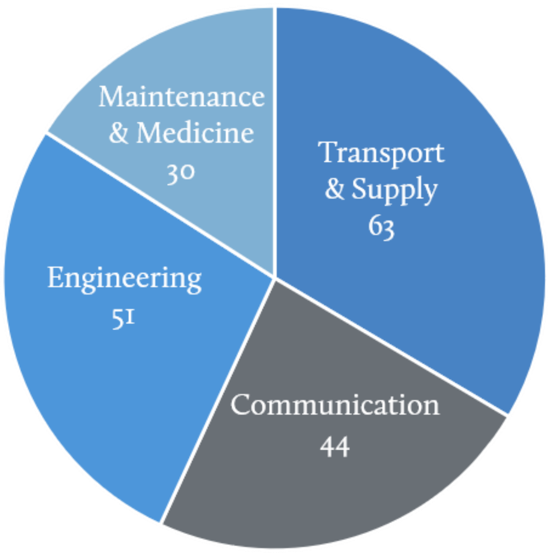

Figure 6: Service and Support Categorization

Defensive/Offensive Use of Force. In regards to **Use of Force**, *Figure 7* displays the **Defensive** RAS, which are divided into **Object**, 55 systems, **Escort** 39 systems, and **Area** 35 systems. Defensive RAS are notably more used for the purpose of Object protection, rather than Area or Escort protection.

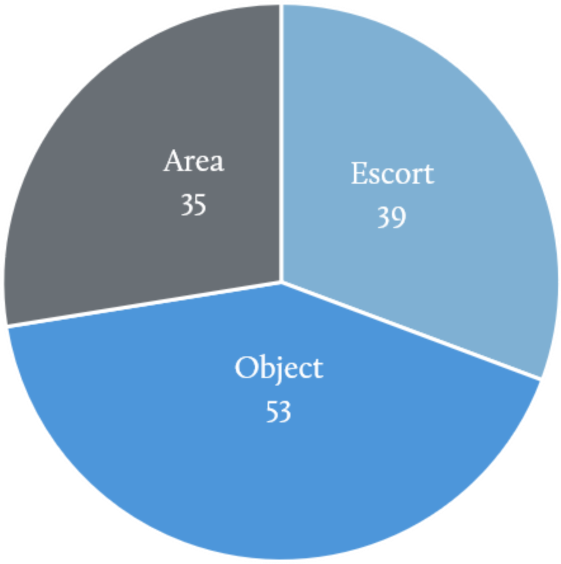

Figure 7: Defensive Use of Force Categorization

On the other hand, *Figure 8* mirrors the **Offensive** RAS, grouped into 65 systems identified as **Lethal** and 6 systems as **Non-Lethal**. A significant discrepancy can be observed between the small amount of non-lethal RAS, in comparison with the amount of RAS that are used for lethal purposes.

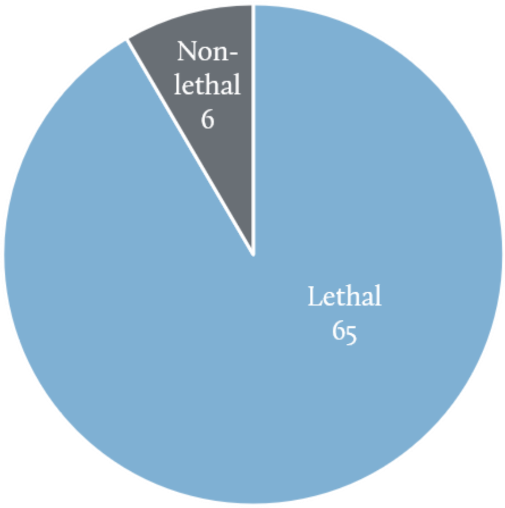

Figure 8: Offensive Use of Force Categorization

4.2 RAS per Country of Origin

Figure 9 visualizes the amount of RAS produced on a global scale. The chart outlines the number of RAS originating from various countries. These include, in a descending order, USA (81), Israel (48), Russia (33), Italy (25), France (23), India (21), China (19), UK (15), Germany (13), South Korea (11) and a cluster of countries in which 10 or less RAS are developed.

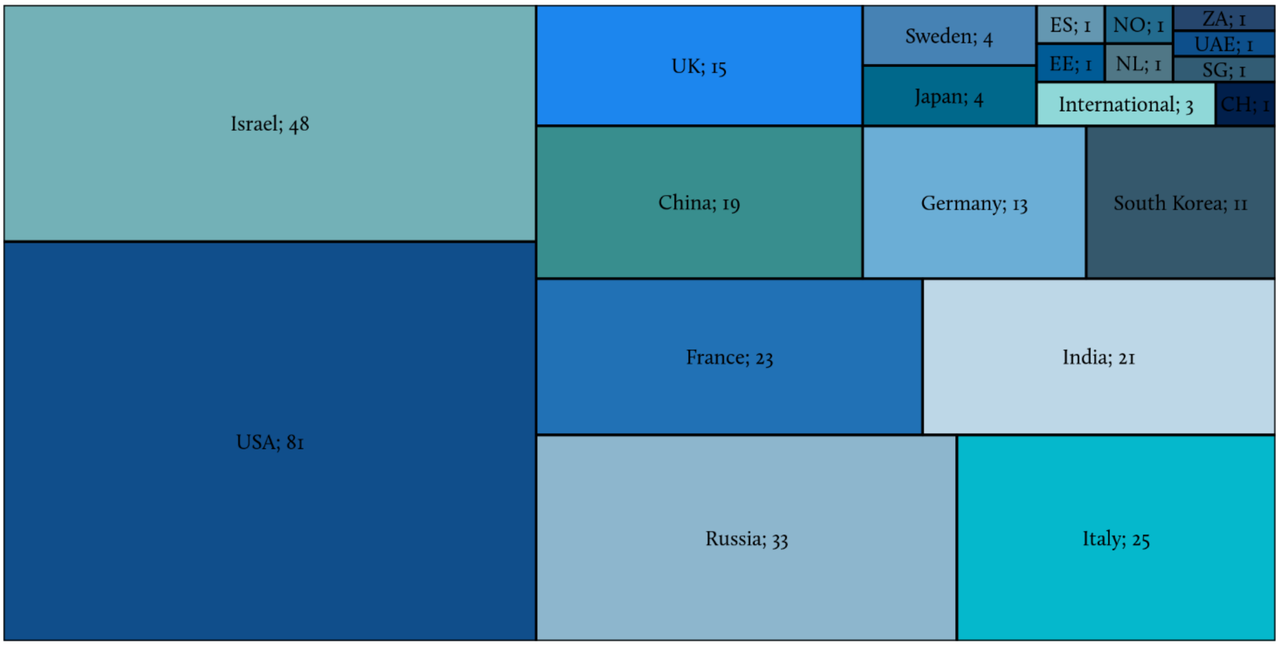

Figure 9: Number of RAS produced per Country of Origin

4.3 RAS per Country of Use

In an attempt to offer a coherent overall view of the global use of RAS, *Figure 10* provides a map presenting the countries that make use of RAS. Additionally, countries were color characterized on the basis of volume: 51-100 projects are marked in red, 21-50 in orange, 11-20 in yellow and 1-10 in purple.

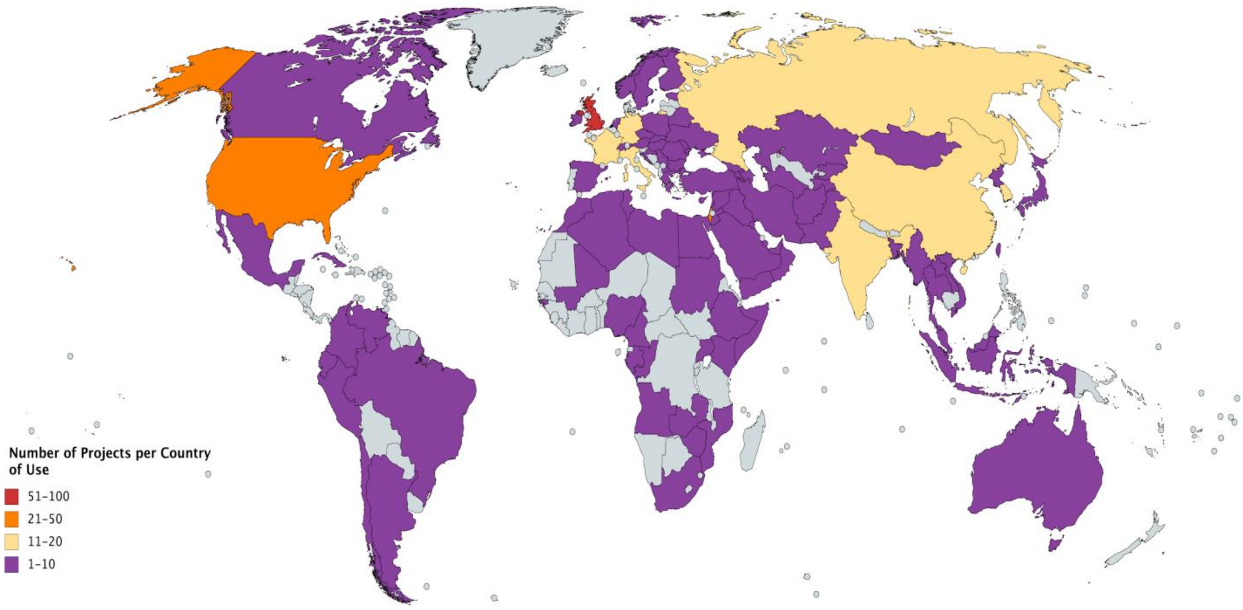

Figure 10: Number of Projects per Country of Use

4.4 Future Applications (Military applicability of RAS for the next 5-10 years)

This section provides an overview of the application areas where RAS could be potentially introduced into the armed forces, with a particular emphasis on land forces in the next five to ten years. Categorized according to tier one of the taxonomy, the findings provided below are based upon the results of an expert workshop conducted by HCSS and the RNLA, combined with an open-source research.

Service and Support.

With regards to the service and support application area, workshop participants noted that RAS could assist or augment a number of human centric solutions, especially in the domains of level 2 of the taxonomy (i.e. transport and supply). For instance, a system used for supplying military equipment, as well as medical evacuation and convoy protection, could provide solutions to tasks that are often considered too dangerous for a human to perform. An example of such a system is the U.S. Crusher UGV. Capable of carrying over 8000 pounds of payload at high-off road speeds and across extreme terrains, Crusher can provide increased mobility, reliability, and logistical support for the army personnel on the ground.[32]

RAS could also be expected to perform various engineering functions, such as C-IED, laying and building bridges, and repairing and maintaining military equipment. When it comes to tasks that have no human-centric alternative, participants pointed out that RAS could be used as mobile communications relay stations and as autonomous recovery systems for RAS. Instead of dispatch manned personnel, such systems could recover damaged equipment, vehicles, and so forth in terrain that is considered dangerous. In this regard, the utility of RAS that are capable of self-healing, self-assembling, and self-repairing is expected to be extremely high in the future to come.[33]

Additionally, RAS can offer effective C3, thus, allowing for the further centralization and increased effectiveness of military command and communication. An example of a system that is capable of performing such functions is the Ground Control System (GCS), identified in the British Army Technology Book. GCS is a platform that enables optimal flexibility between airborne and ground systems, allowing for a more effective command and control during ISR operations.[34]

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[32] National Robotics Engineering Center, "Autonomous Platform Demonstrator."
[33] Nathan Fisher and Gary Gilbert, "Medical Robotic and Autonomous System Technology Enablers for the Multi-Domain Battle 2030-2050."
[34] "Army Warfighting Experiment 2018: Autonomous Warrior," 10.

Information and Intelligence.

In the Information and Intelligence domain, workshop participants indicated that RAS could provide the most military utility in functions such as perimeter monitoring and control—for both in missions abroad and as base protection at home—TA&BDA, and enemy deception. In regards to the latter, a particular example was identified: a system that could deceive the enemy by creating artificial objects used for visual deception. A system of such type is observable in Israel's *Project Hyen*a, which infuses sounds and signatures of real tanks and other vehicles with foldable, semi-autonomous lightweight platforms in order to deceive and provoke enemy objects.[35]

It was also highlighted that RAS could be expected to augment human centric solutions in providing advice to the army by observing, recognizing, and analyzing information autonomously. For instance, *Mantis* UAV allows the UK Defense Forces to perform ISTAR operations, while offering close-air support for ground missions as well as capturing and transmitting , via satellite link, real-time data to the ground control station.[36] Furthermore, in terms of tasks with no human-centric alternative, participants underlined the importance of RAS in providing tactical ISR in urban terrain, i.e. inside of buildings and other urban premises, underground areas, and so forth. The Casper 250 backpack mini UAV is one of the systems that can be operated for this purpose.[37]

Defensive Use of Force.

In regard to defensive use of force, workshop participants underscored the importance of RAS in providing electronic countermeasures as part of area/perimeter protection. The Israeli UGV, Loyal Partner, constitutes such an example which can respond to suspicious attacks and eliminate various threats by using forceful methods, thus protecting manned troops on the ground.[38] RAS could also be defensively deployed in cases of terrorist and/or militia attacks. Participants pointed out to a particular example: a hybrid system—operating in both land and air domains—that would have the ability to attract enemy fire, thus protecting the lives of military personnel on the ground. The HIPPO All Terrain Support Vehicle (ATSV) is a relevant example of a system that can contribute in performing such tasks. With the ability to perform surveillance functions and carry weapons, HIPPO ATSV can provide immense strike effects whilst minimizing the exposure of manned personnel to enemy fire.[39]

[35] Defence Industries, "Https."
[36] Airforce Technology, "Mantis MALE Unmanned Aerial Vehicle (UAV)."
[37] "Casper 250."
[38] Army Recognition Group, "Ground and Aerial Unmanned Vehicles UGV UAV in the Israeli Army Defence Forces."
[39] "Army Warfighting Experiment 2018: Autonomous Warrior."

Offensive Use of Force.

In the offensive use of force application area, workshop participants recognized the ability of RAS to replace traditional jet fighters, such as F-16 and F-35, with sophisticated lethal drones that in the future could fly in swarms. Such a system that is currently under development is the U.S. X-47B Unmanned Combat Air System (UCAS). About the size of an F-16, yet faster and lighter, this UCAS is capable of performing full-fledged jet fighter operations.[40] Additional RAS identified in this application area constitute loitering munitions, and an anti-tank vehicle. In regards to the former, a system that possesses the potential to be applied in the future is the British HERO 30 Tactical Precision Missile System. A lightweight lethal missile system whose preparation and silent launch take less than two minutes, HERO30 is capable of destroying targets at up to forty kilometers in range.[41] In relation to an anti-tank system, the Russian Platform-M UGV constitutes a relevant example. Equipped with anti-tank rockets, Platform-M UGV is capable of performing a wide-range of combat tasks during both day and night with no need to unmask itself.[42] Finally, participants recognized that in terms of tasks with no human-centric alternative, in the future RAS could provide counter-A2/AD measures primarily through saturation tactics.

5 Opportunities and Risks

RAS presents numerous, significant and far-reaching opportunities for the RNLA. To summarize, this includes creating better and faster situational awareness and understanding, reducing the physical and cognitive loads of soldiers, sustaining and protecting the force, extending the reach and persistence of operations, increasing the pace of the OODA loop, and allowing the simultaneous execution of tasks for efficient action. Across all domains, the current human-centric boundaries to speed, knowledge, endurance, scale, accuracy and flexibility will be pushed forward to new, ever-expanding limits. However, with these opportunities come significant challenges, both in terms of practical issues within the military and also in terms of conditional, external issues.

5.1 Practical (Internal) Challenges

Technical.

- The signal communications used by RAS are vulnerable to cyber attacks, including hacking, jamming, 'spoofing', or otherwise impeding the performance of the system. Commercially available software and hardware is capable of achieving these effects.

[40] Smith, "The U.S. Navy Spent $744 Million to Build a Robotic Fighter Jet -- and Now Wants to Throw It Away -."
[41] "Army Warfighting Experiment 2018: Autonomous Warrior," 92.
[42] Army Recognition Group, "Russian Special Forces Have Received Platform-M UGV Unmanned Ground Vehicles."

- In order to facilitate trust in decision making, operators must understand how the system interprets data and delivers actionable information, which can be extremely difficult for highly complex systems.
- Currently, there is a lack of understanding within defense communities of how to operate RAS and how to fix (minor) problems that arise.

Personnel.

- There is currently not enough trust in RAS, especially in high-stake situations, thereby impeding the advancement of man-machine teaming to its full potential.
- Operators may develop overconfidence and/or overdependence on RAS.
- Operators are susceptible to becoming mere acceptors of the 'decisions' made by RAS, without oversight of the algorithmic processes preceding the outcomes. The degree to which humans are meaningfully present in the OODA loop is therefore questionable.
- As new technical experts and data scientists are required and recruited, internal tensions between new technical personnel and traditional soldiers may arise.
- Organizational Culture.
- RAS will certainly lead to changes in terms of training requirements, education, careers and the type of work soldiers engage in. Leadership positions will also change in character.
- Experimentation and rapid innovation do not align with a culture of meticulous planning and linear requirements assessment, development and acquisition processes.
- Inefficient procurement processes can lead to difficulty in keeping up with the speed of technical advancements, in particular for technology developments that are driven by commercial markets.

Doctrinal.

- The integration of RAS and the possibility that machines will replace humans or units in some capacity, will have implications for the doctrine of the Dutch armed forces, but also to the doctrines of allies, such as NATO.

5.2 Conditional (External) Challenges

Perceptions.

- Due to the perpetuation of the "killer robot" image, public perception appears generally negative, despite the nuanced nature of the situation. This dystopian imagery may lead to the requirement of human control across all application areas, regardless of the benefits of automation in most cases.
- It is possible that the use of LAWS will create anti-Western sentiment (and even radicalization) in the areas affected by strikes, due to the perceived indignity and unfairness of being injured or killed by an unmanned system.

Ethical.

- Ethical discourse on RAS focuses on the interplay between offensive and defensive use of force, the necessity of 'meaningful human control' and the question of human dignity.
- There is also an insinuation that RAS may lower the threshold for escalation of conflict due to the dehumanization of the use of force.
- Despots and rogue states, who are less concerned about ethical considerations, may proliferate RAS and more ethical states could subsequently 'fall behind'.
- The acceptance of adverse effects is in proportion with strategic interest. The benefits of broad implementation of RAS may be a higher priority than ethical consideration, and political discourse can reflect this message.

Legal.

- In terms of legality, it is not yet clear exactly how international and national law will adapt to - let alone anticipate - this rapid, and exponential technological change.
- Attribution will become a growing challenge as actors who use RAS will be increasingly able to deflect or avoid responsibility for attacks.[43]

Military.

- Adversaries may face few ethical and legal limitations to the proliferation and use of RAS across all domains.
- The cost of systems that are now considered to be elite will fall. These systems may subsequently be acquired by smaller actors, including non-state actors.

Political.

- RAS represents the next revolution in warfare and powerful states are racing to harness the potential. This will likely lead to an arms race.
- While the state retains a monopoly over the legitimate use of force, other actors such as private military companies, paramilitaries and non-state actors (each with their own agendas) will be involved in the procurement of RAS.

6 Next Steps

These opportunities and challenges imply prerequisite measures for the successful implementation of RAS, as well as ways to mitigate (potential) challenges. Based on knowledge of the current RAS applications in the land domain, the assessment of the military value of RAS, and the identified opportunities and challenges that were identified in the workshop, the following measures were observed by the practitioners, researchers, legal specialists, ethicists, members of the defense community, industry professionals, academics and researchers present during the Expert workshop.

[43] UK Ministry of Defence, "Joint Concept Note 1/18," 23.

These measures represent the insights of this community, derived from a dynamic and inspiring group process during the workshop, on how to proceed with the development of RAS in the land domain. These insights should be used as inspiration for developing strategies and policies, and as basis of knowledge for the next essential steps to be made in the public and political debate on RAS. Legal, ethical and other debates with regard to RAS can only be done sharply if there is a common and good understanding of what the military application of RAS in the land domain means and what is necessary for the inevitable and essential development of this military technology.

The measures are divided into two categories: what should shape the strategies and policies within the army and how to align with other communities. The measures are not prioritized and are all essential in the development of RAS in the military context.

6.1 Within the RNLA

- In order to reap the full potential added value of RAS, concept development & experimentation (CD&E) within the armed forces is urgently needed. This should be done in 'open' configurations, because most of the relevant technology and technology development should be crossed-over from non-military sectors and application areas.
- As the unrestricted use of the cyber and electromagnetic domain is a key requirement for the use of all new technologies in the information age, cyber security and electromagnetic spectrum security, as well as control over the electromagnetic spectrum (in a 'battle over bandwidth' with adversaries), are top priorities to ensure the integrity of RAS. In addition to monetary investment, this requires mandating developers and producers of RAS products to prioritize security and connectivity, actively ensure that their products are free from vulnerabilities, and take timely action to mitigate vulnerabilities that are later discovered.
- Financial investment into AI and systems engineering is vital for the advancement of capabilities such as speed, accuracy, reliability and flexibility. Throughout the development of RAS, there must be a focus on user friendly interfaces with adequate, human-centric checks and balances. During this interim period, it will be necessary to have an online, real-time operator helpdesk to aid operators if needed.
- Education and training programs must address the development of required skills within the organization. The high quality staff needed to develop and maintain RAS (e.g. IT specialists, software engineers), are in short supply and are often lured by attractive salaries in the private sector. Therefore, the RNLA needs to take steps to develop an organizational culture and individual mindset of continuous learning and improving. For the organization, this not only requires

education and training of its current employees, but also continuously searching, identifying, contracting and training new people.

- The training, improvement, and effective maximization of AI requires access to large, high-quality datasets. This requires not only a new kind of knowledge and the implementation of new technologies, but especially highly skilled specialists. Skilled people are the most scarce capability and to attract and keep them on board, a partnership approach is needed.
- A partnership approach, instead of competition, needs to be developed between the private sector and the land forces to facilitate decentralized innovation and CD&E. The RNLA and the Ministry of Defence (MoD) need to adapt in order to make the new Army possible. Organizational culture needs to orient toward innovation and transformation by developing entrepreneurial spirit and facilitating more civil-military collaboration, multi-disciplinary interaction and exchanges of people and knowledge.
- The procurement processes of the MoD must also be adapted toward buying smart systems . This involves a more generous interpretation of European procurement rules and the acquisition of commercial 'off-the-shelf' RAS-capabilities that can be tailored (in close cooperation with industry and knowledge institutes) to military applications. The speed of technological developments in this field requires continuous modifications of systems and implementation of new technologies. Procurement processes need to facilitate this new, permanent Beta approach.
- In order to develop the trust of operators, the system must be predictable, familiar, understandable and appropriate for the context in which it is operating. On a higher level, certification regimes must be established, promoted and implemented. The RNLA has agency in shaping responsible norms around verification of producers and quality assurance of RAS products.

6.2 External to the RNLA

- More understanding and information needs to be disseminated to the public and policy makers regarding the development and use of RAS across all application areas. Ethical standards should be derived from a rich and well-informed debate. The MoD must be active and visible within this national conversation, and transparent in their actions and intentions. Positive aspects of RAS should be emphasized alongside the challenges. The dystopian image of RAS will otherwise lead to the necessity of human control across all domains.
- The MoD must observe and strategically account for the growing capabilities of RAS systems in foreign states. This insight must be debated, politically and publically, and periodically translated into the military strategy for the development of the army. Furthermore, these insights need to be shared with partnering countries and synchronized with the military strategies of these

partners. In our current, developing, globalized and multipolar political system this becomes ever more relevant.

- International legal regimes must work to develop explicit and simple guidelines on autonomy across all application areas, particularly in regard to LAWS. This requires a sharp insight into the targeting cycle of LAWS and the different steps within this process. Added knowledge in this area will bring the focus of the debate to those steps of the targeting cycle that are most contentious. The state of technology and the experiences humans have with these technologies determine the trust in these new technologies and the level of automation or human control. Therefore, the debate on autonomy in military applications will continuously develop.

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