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ROBOTIC MISSION COMMAND – AUTOMATION AND NON-LETHAL AUTONOMY IN MILITARY AFFAIRS

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Automation and autonomous robot adoption by military forces is an inevitable evolution due to fiscal and resourcing economies sought by contemporary states in the achievement of national defence and security objectives. Despite social barriers to their adoption, the defence sector stands to benefit from innovations related to these technologies. While other works have examined lethal autonomous weapon systems, this paper will instead focus upon non-lethal uses of autonomous robots and in which roles they can best contribute to military operational success. This paper argues that the benefits of automation and non-lethal robot autonomy outweigh associated risks of their use and that the rate of adoption of these technologies will be constrained by mission assurance, accountability, and acceptance factors. In order to parse this broad subject into the allowable word limit, preference will be afforded to automated and autonomous technologies which operate in the physical plane of warfare.

This paper will begin by exploring arguments related to autonomy for military applications. It will then define robotic autonomy and compare two models for machine levels of autonomy. Use of robotic autonomy and automation within CAF mission sets will be proposed, concluding with an analysis of factors constraining the pace of adoption of these technologies.

Introduction

Autonomous systems are becoming increasingly popular in both civilian and military sectors. The US Army published its Robotics and Automation (RAS) Strategy in 2017 which highlighted realistic, feasible, and visionary RAS objectives on the horizon as well as hosting its inaugural Autonomy and artificial intelligence (AI) conference for government and industry in Fall 2018.[1] Major weapon manufacturers are developing autonomous submersible vessels for global superpowers such as China that could be used for surveillance, payload delivery, or even colliding with other surface or sub-surface vessels.[2] Australian Defence Force researchers are exploring the 'mother ship' concept, where air power roles are delivered through controlling numerous independent, semi-autonomous aerial vehicles.[3] Civilian industry has heavily invested in autonomous vehicle technologies prompting the Society of Automotive Engineers to define vehicular automation levels into six defined categories recognized by the US Department of Transportation.[4] NASA uses autonomous systems for the Curiosity Rover in order to explore distant planets currently inaccessible by humans.[5] But is autonomy beneficial?

Debating Automation & Autonomy

Contemporary society as changed dramatically since the Luddites, an early 19th century people protesting against labour-replacing machines, destroyed textile mill machines used to refine cotton and wool to preserve their livelihood.[6] The internet has broadened our global perspective and increased communication intermediation, human

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[1] US Army Conference: Autonomy and AI to enable multi-domain operations, held 28 & 29 Nov 18 in Detroit, MI, details at: https://www.ausa.org/army-autonomy-ai-symposium; US Army Capability Integration Center, Robotic and Autonomous Systems (RAS) Strategy, details at: https://www.tradoc.army.mil/Portals/14/Documents/RAS_Strategy.pdf.

[2] https://www.scmp.com/news/china/society/article/2156361/china-developing-unmanned-ai-submarines-launch-new-era-sea-power.

[3] Australian Defense Force Journal, *Air Power in the 21st Century,* Issue204, March 2018: http://www.defence.gov.au/ADC/ADFJ/Documents/issue_204/ADFJournal204_Air_power_in_the_21st_century.pdf

[4] Vehicle autonomy level 0: No automation through to level 6: Full automation. Details at: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#issue-road-self-driving

[5] T. Fong, NASA presentation on Autonomous Systems in space, Aug 18, details at: https://www.nasa.gov/sites/default/files/atoms/files/nac_tie_aug2018_tfong_tagged.pdf)

[6] Richard Conniff, "What the Luddites Really Fought Against", Smithsonian Magazine, Mar 18.

population has reached record numbers, and resources on Earth are becoming increasingly precious and are consequently becoming a source of conflict. As much as the environment surrounding humans has changed, there are those who still possess an underlying notion of Robophobia.[7] Whether the fear stems from the residual belief that automated machines will cause unemployment, that killer robots will gain their own consciousness and have no use for humans, or that the loss of human life by an autonomous vehicle is more devastating than the hundreds of lives lost daily by human drivers, humans remain naturally skeptical about the safety, security, and use of autonomous machines.[8]

Despite the misconceptions and perceptions, there are favourable arguments supporting non-lethal autonomous robotics and automation within military contexts:

Benefit #1: Fiscal economies

The cumulative cost of an American enlisted soldier with salary, health and retirement benefits, serving a 20 year career was $867,833 USD according to a 2007 RAND study.[9] This price tag was exclusive of all allowances related to operational deployments, any temporary duty costs or specialized training required, as well as provision of basic need costs while employed or deployed such as sleeping quarters, water, food, sanitary, equipment, etc. which was estimated at $2.1M USD per soldier, per year deployed.[10] Modern militaries are being called upon to do more with less as global

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[7] Graham Davey, *Phobias: A Handbook of Theory, Research and Treatment,* Wiley, 1997; Robophobia: Irrational fear of robots, drones, robot-like mechanics, or artificial intelligence.
[8] Kevin LaGrandeur, *Androids and Intelligent Networks in Early Modern Literature and Culture: Artificial Slaves,* Routledge, 2012.
[9] Carl J. Dahlman, "The Cost of a Military Person-Year: A Method for Computing Savings from Force Reductions", RAND Corporation, 2007.
[10] Todd Harrison, "Chaos and Uncertainty: The FY 14 Defense Budget and Beyond", Center for Strategic Budgetary Assessments, 2013, https://csbaonline.org/research/publications/chaos-and-uncertainty-the-fy-14-defense-budget-and-beyond/.

governments seek budgetary economies and as inflation and labour costs continually appreciate. Automating basic tasks using machines would reduce the number of human support personnel required to deploy into operational theatre and could result in significant fiscal economies. Increasing levels of machine autonomy could mean fewer humans required in military operational or support roles, thereby providing a solution to militaries which struggle with recruiting and retention issues.[11]

Benefit #2: Efficiency & effectiveness

Machines are not subject to the mortal constraints of basic needs and can perform tasks without the need for sleep, water, or air. This enables automation to occur around the clock while humans focus on the hierarchy of needs and the more complex issues at hand. Machines are well suited to tasks that demand precision, speed, or repetitive actions, thereby reducing strain upon humans as well as the possibility of human error. Ambitious military leaders strive to produce greater output with a fixed amount of personnel, inducing increased stress which potentially results in subordinate burnout. Automation of simple functions can provide an avenue to increase human resource productivity by reduction of overall task burden.

Benefit #3: Reduced risk & lives saved

Though autonomous robots may not be the preferred solution in every military scenario, their use in hazardous or potentially lethal environments, such as in space or underwater, reduces the likelihood of human death. Human risk cannot be entirely mitigated using machines, as the nature of chivalrous combat and the Law of Armed

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[11] Matthew Gillis, "The Future of Autonomous Marine Systems in the Canadian Navy", Canadian Naval Review, Vol. 6, No. 4, Winter 2011, http://www.navalreview.ca/wp-content/uploads/public/vol6num4/vol6num4art5.pdf.

Conflict must be upheld. Using human resources for high priority, highly complex, and no-fail mission assurance situations will be the norm until robotic technologies are able to outperform their biological counterparts. Due diligence in robot design is crucial to ensure that the autonomous robots created to conduct military missions do not instead cause the unintended loss of human life.

Understanding Automation & Autonomy

Automation is the automatically-controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labour.[12] Whereas *autonomy* is the ability of a system to achieve goals while operating independently of external control.[13] An autonomous system requires both *self-directedness*, to achieve goals, and *self-sufficiency*, to operate independently. Although autonomous systems usually rely upon automated processes, such as pre-programmed instructions to respond to certain conditions, automation does not imply autonomy.[14]

Robots are machines which operate and interact within the physical plane and may either be remotely controlled or possess a degree of autonomy. It follows that autonomous robots and are capable of independent task fulfilment without external control, operating through movement, action, or manipulation of the surrounding physical environment. Innovations in automation algorithms and artificial intelligence enables autonomous robots to perform increasingly complex tasks.[15]

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[12] Merriam-Webster Online Dictionary, 2019, https://www.merriam-webster.com/dictionary/automation.
[13] Terry Fong, “Autonomous Systems: NASA Capability Overview”, presentation, 24 Aug 18.
[14] *Ibid.*
[15] *Ibid.*

Robotic autonomy is by extension: The extent to which a robot can *sense* its environment, *plan* based on that environment, and *act* upon that environment with the intent of reaching some *task-specific goal* (either given to or created by the robot) without external *control*.[16]

The initial considerations when designing a robot that can independently perform actions are the detailed analysis of expected *task*s assigned to the machine and the *environmental context* in which the tasks are to be performed. Variables to consider during the initial design stage are: Task criticality, task accountability, and environmental complexity. Three crucial sub-components of a robot's overall task: Sense, plan, and act, may have dramatically different levels of capability and autonomy which inevitably determines the required level of human intervention. These factors combined are used to categorize a system's autonomy level as indicated in guideline 4 of figure 1.

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[16] Jenay M. Beer, Arthur D. Fisk, and Wendy A. Rogers, "Toward a Framework for Levels of Robot Auonomy in Human-Robot Interaction", Journal of Human-Robot Interaction, Vol. 3, No. 2, 2014.

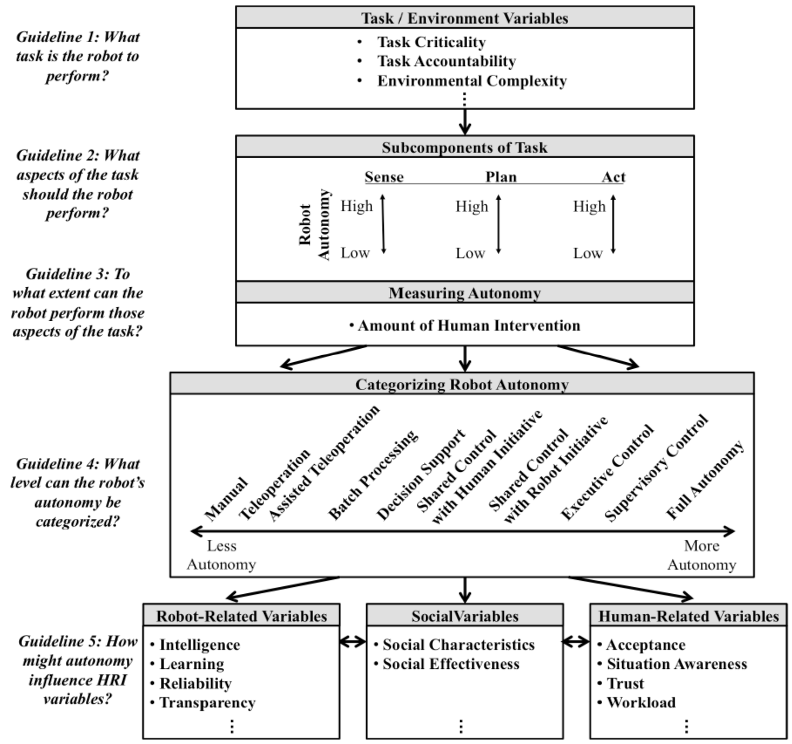

Figure 1. Framework for the design of autonomous robots. Human-Robot interaction (HRI) variables are the final consideration once task and environmental factors have been determined.[17]

While the Beer et al. framework provides a conceptual model for design and categorization of robotic autonomy, an earlier work by NASA details 8 distinct levels of autonomy through an assessment scale based upon Boyd's recursive observe-orient-decide-act (OODA) loop.[18] See figure 2 for a matrix of each autonomy level corresponding to OODA activities accompanied by descriptions. Beer's framework uses the terms sense-plan-act, which can be transposed to Boyd's OODA activities simply by dividing the *plan* task sub-component into two sub-components: *orient* and *decide*.

[17] *Ibid.*

[18] Ryan W. Proud, Jeremy J. Hart, and Richard B. Mrozinski, "Methods for Determining the Level of Autonomy to Design into a Human Spaceflight Vehicle: A Function Specific Approach", NASA, 2003.

Level	Observe	Orient	Decide	Act
8	The computer gathers, filters, and prioritizes data without displaying any information to the human.	The computer predicts, interprets, and integrates data into a result which is not displayed to the human.	The computer performs ranking tasks. The computer performs final ranking, but does not display results to the human.	Computer executes automatically and does not allow any human interaction.
7	The computer gathers, filters, and prioritizes data without displaying any information to the human. Though, a "program functioning" flag is displayed.	The computer anlayzes, predicts, interprets, and integrates data into a result which is only displayed to the human if result fits programmed context (context dependant summaries).	The computer performs ranking tasks. The computer performs final ranking and displays a reduced set of ranked options without displaying "why" decisions were made to the human.	Computer executes automatically and only informs the human if required by context. It allows for override ability after execution. Human is shadow for contingencies.
6	The computer gathers, filters, and prioritizes information displayed to the human.	The computer overlays predictions with analysis and interprets the data. The human is shown all results.	The computer performs ranking tasks and displays a reduced set of ranked options while displaying "why" decisions were made to the human.	Computer executes automatically, informs the human, and allows for override ability after execution. Human is shadow for contingencies.
5	The computer is responsible for gathering the information for the human, but it only displays non-prioritized, filtered information.	The computer overlays predictions with analysis and interprets the data. The human shadows the interpretation for contingencies.	The computer performs ranking tasks. All results, including "why" decisions were made, are displayed to the human.	Computer allows the human a context-dependant restricted time to veto before execution. Human shadows for contingencies.
4	The computer is responsible for gathering the information for the human and for displaying all information, but it highlights the non-prioritized, relevant information for the user.	The computer analyzes the data and makes predictions, though the human is responsible for interpretation of the data.	Both human and computer perform ranking tasks, the results from the computer are considered prime.	Computer allows the human a pre-programmed restricted time to veto before execution. Human shadows for contingencies.
3	The computer is responsible for gathering and displaying unfiltered, unprioritized information for the human. The human still is the prime monitor for all information.	Computer is the prime source of analysis and predictions, with human shadow for contingencies. The human is responsible for interpretation of the data.	Both human and computer perform ranking tasks, the results from the human are considered prime.	Computer executes decision after human approval. Human shadows for contingencies.
2	Human is the prime source for gathering and monitoring all data, with computer shadow for emergencies.	Human is the prime source of analysis and predictions, with computer shadow for contingencies. The human is responsible for interpretation of the data.	The human performs all ranking tasks, but the computer can be used as a tool for assistance.	Human is the prime source of execution, with computer shadow for contingencies.
1	Human is the only source for gathering and monitoring (defined as filtering, prioritizing and understanding) all data.	Human is responsible for analyzing all data, making predictions, and interpretation of the data.	The computer does not assist in or perform ranking tasks. Human must do it all.	Human alone can execute decision.

Figure 2. Levels of autonomy assessment matrix.[19]

The two models above indirectly support the concept that an increased level of machine autonomy does not always represent the preferred outcome. Instead, machine autonomy level should be based upon both task and environmental variables, including whether a robot would be operating in isolation, as a member of a team of other autonomous robots, or as a member of a mixed human-robot team. In the case of the latter, thorough social interaction design would be essential to ensure that roles, responsibilities, and protocol between human and robot team members were well

[19] *Ibid.*

understood by each team member. Military operational applications of autonomy will be explored based upon the two aforementioned autonomy models.

CAF Robotic Mission Command

Although fully autonomous robotic systems for military applications do not exist today, due consideration must be afforded to the use of automation and semi-autonomous systems within military operational scenarios. This section will begin by describing the contexts in which autonomy and automation could be employed in military operations, then conclude with an examination of constraints for their use.

Extreme or communication-constrained environments

As the Arctic, space, and deep sea regions become increasingly contested by nation-states due to their rich-resource potential, so do these regions become conflict zones. Deploying humans to any of these regions imposes great life-support system constraints which can be otherwise eliminated through the use of autonomous air, land, and seafaring platforms which can patrol, assist in search and rescue missions, and provide vital geomatics and intelligence support in the defence of Canada. Likewise, the use of autonomous robots have clear potential to operate for extended periods of time without human exposure to the detrimental effects of hazardous operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) environment.

Tasks involving great risk to human life

Remotely controlled robots are used by several military and police forces around the globe to conduct explosive ordinance disposal. However, unmanned and autonomous vehicles equipped with flails could be employed for automated route clearance, sea demining operations, for the suppression of enemy air defences, or to support ground forces for checkpoint security during urban operations or in ever growing mega-cities.[20]

Logistic-related tasks

Resupply and replenishment operations, maintenance of vehicles and equipment, asset management, movements, and even food preparation are all tasks which could be automated and benefit from some degree of machine autonomy. Leader-follower convoy operations, unmanned warehouses, automatic replenishment, procurement, and reception of consumable items, issuing and delivery of goods, material audits, stocktaking and even transport all have great potential for automation and autonomy.[21]

Engineer support for humanitarian assistance

Following a natural disaster there is an immediate and persistent need for situational awareness via imagery, geomatics, and spatial near real-time data. A small fleet of autonomous drones self-launched from a pod serving as a recharge and download platform would facilitate information collection and distribution. As robotic construction and demolition removal teams emerge, they could be used to rebuild infrastructure and clear debris or remove remnants from war torn areas.

Medical laboratory support

As healthcare experts practice medicine based upon the evaluation and testing of patients, an automated medical station could be deployed to remote forward operating bases to conduct routine health evaluations by taking urine, stool, or blood samples. If not equipped with a remote communication module to send patient data to a human doctor,

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[20] Joel Lawton, Matthew Santaspirt, Michael Crites, and Lori Shields (ed.), "Army Operations in Megacities and Dense Urban Areas: A Mad Scientist Perspective", US Military Intelligence Journal, 2016.
[21] US Army Capability Integration Center, Robotic and Autonomous Systems (RAS) Strategy, 2017.

the deployable medical station could employ its autonomous prognosis database to provide information to patients.[22]

Robotic wingman

Before the advent of fully autonomous robotic systems, a necessary evolution of HRI systems would need to occur. Systems that are able to learn and adapt to environmental and task sub-component changes, as well as function as part of a mixed human-robot team, are the next logical evolution.[23] A robot training academy would introduce human to machine, such that humans and their autonomous robot platform would learn to interoperate. Whether on land, at sea, or in the air, a robotic platform could provide its human teammate with enhanced survivability, communication, and intelligence gathering tools.

Constraining EVE

For certain military scenarios, autonomous robots may not be suitable due to an unpredictable environmental context or issues related to mission assurance, accountability, or even acceptance from humans involved in the mission. Whether autonomous robots would favourably handle unexpected scenarios remains the single greatest obstacle to the advancement of these technologies. Human confidence in machines is built with time-based experience, understanding, and repeated predictability.

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[22] Robert M. Wachter, *The Digital Doctor: Hope, Hype, and Harm at the Dawn of Medicine's Computer Age,* McGraw-Hill Education, 2015.
[23] Valerie Insinna, "Under Skyborg program, F-35 and F-15EX jets could control drone sidekicks", Defense News, 23 May 2019, https://www.defensenews.com/air/2019/05/22/under-skyborg-program-f-35-and-f-15ex-jets-could-control-drone-sidekicks/.

Constraints upon the use of autonomous robotic and automation technologies for military purposes such as mission assurance, accountability, and acceptance will be discussed.

Mission Assurance

A mission first attitude is a defining attribute of those who wear or have worn the cloth of their nation. It is expected that a nation's military succeed in its assigned strategic mandate, particularly during government endorsed campaigns, where return on investment is subject to public scrutiny. Given the wide variety of mission sets that the CAF can be expected to respond to, from peach support operations to war, it is reasonable to reject the notion that a multi-role, autonomous robot will ever replace a human in uniform.[24] Particularly at this nascent stage of modern autonomous robotic technology development, missions with relatively low complexity, limited HRI, and moderate mission assurance should be assigned to machines in order to achieve critical inertia and fuel future research and development.

Warfare is chaotic and uncertain, with a fog shrouding situational awareness and understanding in the most dynamic of contexts. Cognisant of the complexity of war, autonomous systems are best initially employed as part of a mixed human-robot team in the accomplishment of combat support tasks. Mission assurance is held in high regard within military constructs, which is likely why machine autonomy development efforts have been correspondingly constrained by mission assurance principles, due to the driving need for reliability and predictability in uncertain situations.

Accountability

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[24] Canada, Department of National Defence, *CFJP 1.0: Canadian Military Doctrine*, 2009.

Who is accountable when an autonomous machine or an automated process commits an unintended act that causes harm or damage? Applicable laws point to three sources of accountability for autonomous systems: the State under the Law of State Responsibility, the Manufacturer under the Law of Product Liability, and potentially the military Commander who is employing autonomous systems under International Criminal Law.[25] Non-coincidentally, there is a multi-year, multi-million dollar program that DARPA is working on called *Explainable Artificial Intelligence (AI)*, which is believed to be a de-risking activity to enhance reliability and predictability of autonomous systems through de-mystification of the algorithms inside the AI black-box.[26] Although the United States government is doing due diligence to research the legal ramifications of autonomous systems, not every state government is compelled to adhere to international statutes and codes of armed warfare.

Although many of the legal foundations for use of autonomous systems have not yet been created, there is government recognition that legislation for similar vehicle-related technologies is required. In 2016, the Province of Ontario launched a 10-year pilot program to allow the testing of automated vehicles on Ontario roads.[27] Since 2012, 41 American states have considered legislation of autonomous vehicles.[28] With the potential for autonomous systems to reach significant technological milestones in coming years,

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[25] Neil Davison, "A Legal Perspective: Autonomous Weapon Systems under International Humanitarian Law," International Committee of the Red Cross, UNODA Occasional papers, no. 30, Jan 2018, 5.
[26] Natalie Salmanowitz, "Explainable AI and the Legality of Autonomous Weapon Systems," *Lawfare article*, Nov 2018.
[27] Ministry of Transport Ontario, "Automated Vehicle Pilot Program", 2016: http://www.mto.gov.on.ca/english/vehicles/automated-vehicles.shtml.
[28] National Conference of State Legislatures, "Autonomous Vehicles: Self-Driving Vehicles Enacted Legislation", 2019: http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

legislative statutes must be drafted and shaped by informative studies and potential military use cases.

Acceptance

The public remains cautiously intrigued in machine autonomy, with some skeptics calling for an outright ban on their creation. In an effort to reduce barriers to autonomous system adoption and increase public trust in their use for defence and security purposes, the Canadian government released a second call for proposals in 2018 as part of the Innovation for Defence Excellence and Security (IDEaS) and received 26 applications.[29] It is simpler to design autonomous robots which operate far from the public in remote or bio-hazardous environments as the physical isolation prevents inadvertent harm or damage. However, for self-reliant and self-sufficient machines to be capable of accomplishing military objectives, public trust and acceptance must be first established in order to perform functions within the proximity of the populous. Furthermore, they must be programmed or trained in a manner such that human customs, protocol, language, and behaviours are understood such that the development and ultimate use of autonomous systems is unconstrained by societal perception biases.

Conclusion

Canadian Armed Forces are well postured to be a global leader in autonomous robotic and automation technologies, as Canada is perceived as a less-threatening and relatively pacifistic nation with predominantly uncontested borders. Investment in the development of non-lethal robotic technologies would pave the way for Canadian

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[29] https://www.canada.ca/en/department-national-defence/programs/defence-ideas/past-opportunities/cfpmn-2-autonomous-systems.html; https://www.canada.ca/en/department-national-defence/programs/defence-ideas/list-accepted-letters-mnn.html

industry and bring notoriety on the global stage. Continuing the enduring Canadian legacy in the field of robotics, as with the Canadarm on the space shuttle orbiters, the government would be wise to foster innovative robotic technologies, using the CAF as a testbed for trialing and integrating newer systems. As evident from recent media reports, Ottawa is emerging as a desirable global autonomous vehicle testing location due to its extreme seasonal temperature and climatic variance.[30]

Autonomy is only mentioned twice in the latest National Defence policy: Strong, Secure, Engaged.[31] Though innovations in this field tend to come from advances in commercial and industrial sectors, the military should be filling the driver's seat when it comes to development of autonomous robotic systems for military applications.

The increased use of autonomous systems, such as robots, is an unavoidable conclusion and militaries around the globe are seeking to maximize the use of both automation and autonomous technologies. As autonomous systems become more prevalent and their tactical-use more institutionalized, humans will have more time to dedicate to tasks of greater complexity, such as the planning and fulfillment of operational and strategic level objectives.

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[30] Kate Porter, "'Mini-city' for self-driving vehicles launches in Greenbelt", CBC News, May 2019: https://www.cbc.ca/news/canada/ottawa/autonomous-vehicle-test-track-launch-1.5140703

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