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An Introduction to Automation and Artificial Intelligence

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Paper 8

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The Freeman Air and Space Institute is an inter-disciplinary initiative of the School of Security Studies, King's College London. The Freeman Institute is dedicated to generating original knowledge and understanding of air and space issues. The Freeman Institute seeks to inform scholarly, policy and doctrinal debates in a rapidly evolving strategic environment characterised by transformative technological change which is increasing the complexity of the air and space domains.

The Freeman Institute places a priority on identifying, developing and cultivating air and space thinkers in academic and practical contexts, as well as informing, equipping and stimulating relevant air and space education provision at King's and beyond.

The Institute is named after Air Chief Marshal Sir Wilfrid Freeman (1888–1953), who was crucially influential in British air capability development in the late 1930s and during the Second World War, making an important contribution to the Allied victory. He played a central role in the development of successful aircraft including the Spitfire, Lancaster and Mosquito, and in planning the wartime aircraft economy – the largest state-sponsored industrial venture in British history.

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An Introduction to Automation and Artificial Intelligence

Professor Martin Parr

About the Author

Martin Parr is an honorary professor at the University of Kent and a Senior Principal Consultant at the UK Government's Defence Science and Technology Laboratory (Dstl). Martin has researched the design and development of intelligent systems in private industry before moving into various government advisory roles. Martin has provided advice to UK government programmes that have annual budgets in excess of £1 billion, including the Ministry of Defence test and evaluation programme. Martin has been Co-Chair of a NATO international research group that has considered 'The Cost Related Implications of Autonomy from a System of Systems Perspective.' Martin regularly teaches at the Defence Academy and on the University of Kent's MBA programme. Martin is a Chartered Engineer, a Fellow of the Institution of Engineering and Technology and a Fellow of the Operational Research Society.

Abstract

Ever since the industrial revolution people have looked for imaginative ways of delivering a product or service with reduced labour. Some systems offer the same outcome using less resource. Other systems provide a better or different outcome, but if the outcomes are different it makes efficiency very difficult to judge. This paper looks at the beginnings of autonomy and Artificial Intelligence (AI). It then considers the benefits that autonomy and AI are providing for commercial companies such as Amazon, where robotic systems have led to a 22% fall in operating costs. The paper explores why there is a first adopter advantage within this technology and considers where autonomy and AI are enhancing air and space organisations. It contrasts the civilian commercial applications of this technology, such as Amazon, with the challenges in the air and space organisations, along with the risks in this new technology. The paper concludes by considering a possible direction for the future for air and space, along with the gap between the possible and acceptable uses of this technology.

The Journey Towards Automation and Artificial Intelligence

Automation captured the imagination of the early Egyptians and Greek communities who built humanoid 'Automata', simple self-operating machines that follow a predetermined set of instructions.[1] Examples are automated looms and 'player pianos' that played songs where the musical notes that were to be played were represented by holes in a paper piano roll. Modern automation is defined as 'the use of machines and computers to operate without needing human control'.[2]

Ever since the industrial revolution people have looked for imaginative ways of reducing the labour required to deliver a product or service. Adam Smith highlights two ways to do this: (1) division of labour, such as a production line, where workers are extremely efficient at a specific task, (2) improvement in technology and tooling. Smith observes that a team of two men with three horses and a plough can prepare more land than twenty men with shovels.[3] Machines such as electric saws reduce the time and therefore cost of delivering goods and services. But modern machines do more than just reduce cost. Automated machining systems are highly accurate, so they also improve the quality of the final product. While the plough saved human hours, other types of automation such as a computerised spreadsheet have offered an improved capability. This came with enhanced cost, so a spreadsheet would be placed in the top left quadrant in Figure 1.[4] Figure 1 shows that new ways of implementing an approach may change efficiency (the time and cost of performing a task) and/or the capability (providing higher quality output).

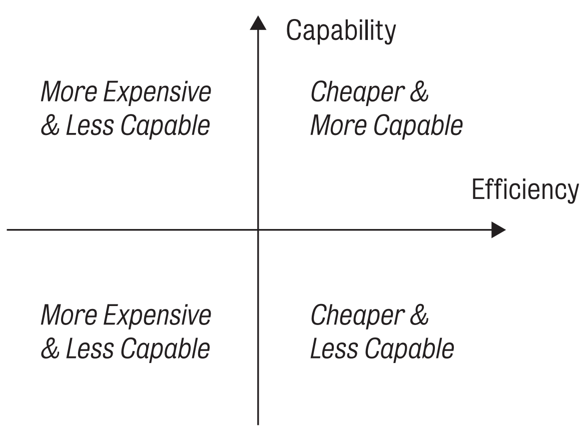

Figure 1: Efficiency and Capability

'Automation' was first used in its present context by D. S. Harder, at the Ford Motor Company in 1946. The automotive industry had a strong interest in substituting human labour with mechanised systems to improve efficiency and provide a better capability (in delivering better products with lower human health risks) through removing humans from dull or hazardous tasks, such as spraying car bodywork or machining. In the early days the benefits anticipated were that humans could enjoy leisure time while the robots worked.[5]

An early example of automation in a military context was a British Army bomb disposal robot known as Wheelbarrow – the first prototype was a modified mechanical wheelbarrow, bought from a garden centre.[6] This formed the basis of today's bomb disposal robots which have saved many human lives. This is an example of automating to improve capability (saving of lives) rather than to reduce labour costs. Therefore, the Wheelbarrow would be in the top left quadrant of Figure 1 as the automated system has a purchase and maintenance cost but doesn't remove human effort from bomb disposal tasks; it just keeps the human operators away from the danger area. Therefore, the Wheelbarrow enhances capability in that it reduces the risk to human life.

The development of Artificial Intelligence (AI) has seen a number of successes but also some setbacks since the 1950s, the decade considered to be the birth of modern AI technology. AI can be defined as 'the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings'.[7] AI stagnation has occurred in periods of time known as 'AI winters' (a term borrowed from 'nuclear winter'[8]). This was due to a lack of funding, inadequate computing power, and key influencers expressing negative opinions about AI systems. Modern AI has seen breakthrough after breakthrough. Development is accelerating, especially in fields such as machine and deep learning. AI and automation are vital components in 10 of the 15 biggest ideas in disruptive innovation for the next decade. These ideas were proposed by Catherine Wood, one of the most successful private sector investors of the last few years. These include orbital aerospace, drone delivery, autonomous ride hailing, and robotics.[9]

Automation and AI are being developed predominantly by academics and industrial and commercial organisations. The Fourth Industrial Revolution is a term used to describe 'the blurring of boundaries between the physical, digital, and biological worlds', referring to the fusion of advances in AI, robotics, the Internet of Things (IoT), 3D printing, genetic engineering and quantum computing.[10] In November 2020, the British government recognised the importance of innovation in these fields with its top priority in the new 'Industrial Strategy' being 'to put the UK at the forefront of the artificial intelligence and data revolution'. An additional £16.5 billion was allocated by the UK government to future defence programmes, including the development of AI, cybersecurity, and space operations.[11]

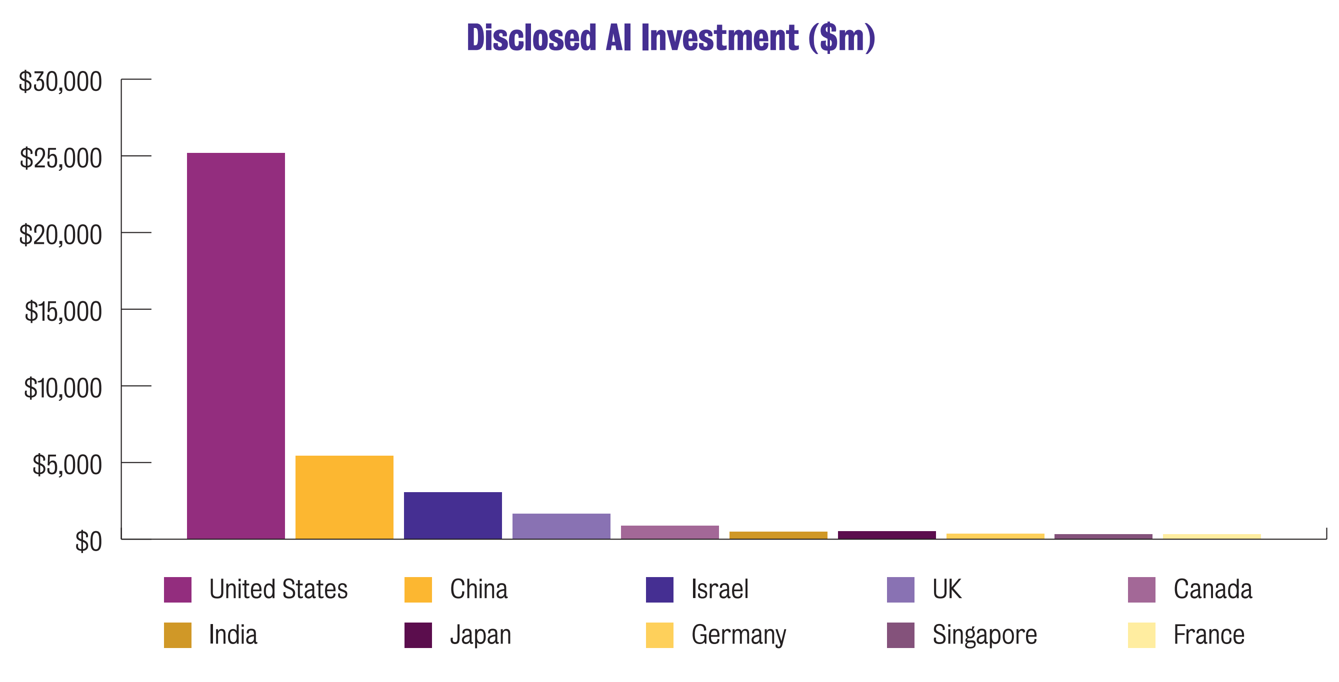

Figure 2: CSET analysis of Crunchbase and Refinitiv data. Ordered by disclosed investment value in 2019.

The strategy aims to push the UK ahead because AI has a first adopter advantage, especially in the context of national defence and peace keeping. The idea of first adopter advantage is more specific to AI than may be immediately obvious. Firstly, AI systems can take time to configure and optimise for a given task, and so early adopters will derive more immediate reward and expertise which can then be compounded significantly. Secondly, exploiting AI requires access to large amounts of high-quality data to train new algorithms. The first movers can begin to accumulate large data sets in the right format and of the highest quality. Therefore, this enables their AI technology to be superior to that of later adopters. Early adoption will involve more cutting-edge research and the costs of this will be considerable. New branches of military systems have always had to find funding for their infrastructure. The first military aircraft needed a runway and training of maintenance staff etc.

Figure 2 highlights the disclosed levels of investment in AI within some key nations. While all figures of this sort are likely to be very rough estimates, particularly the figures from nations that are less willing to disclose their research interests, it does provide some indication of the levels of investment. It also provides an indication that the UK may now be a significant investor in this technology, given the 2020 enhancements to UK government funding.[12]

Why use Automation and AI? What benefits does this technology bring for Commercial and Industrial Organisations?

Factories automate to save labour costs, speed up production, and produce better-quality products. In many cases robots are more accurate and consistent than humans. According to the Financial Times, the two robotic systems Ocado acquired in 2020 will save £7 million per year in each fulfilment centre when they are rolled out, cutting non-administrative operating costs.[13] This will double Ocado's margins compared with the industry average. A margin is the difference between a company's costs and its sales income. Ocado is already in the process of eliminating human labour associated with picking, packing, and decanting (breaking down incoming stock into smaller items so that it can be catalogued and stored). This is doubling Ocado's pick and pack speed. Credit Suisse suggest that, theoretically, Ocado could become even lower cost than a customer doing their own shopping.[14] If this were possible, developing such a cost advantage would offer a company a huge competitive edge.

One of the benefits of AI and automation is speed. This is especially important in the financial markets. Algorithms which execute and match orders vastly improve efficiency and increase the liquidity of various asset markets. Hedge funds and banks are always looking for ways to speed up information flow and are willing to pay premium prices for what may seem like insignificant time savings. In 2013 a $300 million transatlantic fiber-optic link called Project Express was installed, creating a time saving of 5.2 milliseconds, giving high frequency traders billions of pounds in monetary gains since it was first used.[15]

Similar efficiency gains have been realised by Amazon; their acquisition of Kiva Robotics has led to a 22% fall in operating costs.[16] Now at least 200,000 robotic vehicles are operating in Amazon's fulfilment warehouses. These robots execute tasks in a quarter of the time taken by human staff. The warehouses can also hold up to 50% more stock as the machines need less space than the human staff.[17]

A relatively unknown and niche area of the private sector that is quite literally on the cusp of 'taking off' is the eVTOL industry. eVTOL is an acronym for 'Electric Vertical Take-Off and Landing'; this technology has a striking resemblance to Sci-Fi ideas and predictions of the future from the past few decades. Companies such as EHang, Lilium, and CityAirbus are aiming to revolutionise urban mobility. EHang have developed an autonomous aerial vehicle (essentially a big drone) that can be hailed for passenger use in the same way that Uber and Lyft have revolutionised the traditional taxi industry. EHang have conducted hundreds of flight tests with human passengers and have demonstrated the drone's capabilities for passenger journeys and also extinguishing fires in skyscrapers. With a maximum payload of 220kg the drones can fly at 130km/h for a range of 35km.[18]

What benefits does this technology bring for Air and Space Organisations?

The previous commercial examples highlight implementing automation because it reduces cost, and sometimes improves quality. In the commercial world this will maintain a competitive advantage. But there are instances in which human's don't have time to make decisions. The Curiosity rover is studying the rocks and terrain on the surface of Mars. It can take over five minutes to transfer images back to earth, which means that the rover could have been driven into a valley or obstacle by the time scientists can see the view from Curiosity's windscreen and steer it onto a suitable path. So, Curiosity uses computer vision and a deep learning algorithm to analyse its surroundings and plan its own directional path, all before a human could receive a picture.[19] There are similar requirements in satellite-based systems where bandwidth rather than time is limited. Transmitting all the collected data down to earth may not be possible, so in-orbit processing and decision making would mean that more of the data collected can be used for human decision making and situational awareness.

NASA currently uses AI for scanning deep space and creating 3D models of asteroids to identify threats to the earth. The software uses Neural Networks to measure asteroid size, shape and spin rate. This AI based tool takes four days to categorise an object as threat or 'non-threat' compared with an average of four months for a human astronomer.[20]

One of the more discreet yet extremely powerful uses of automation in defence is in improved data analytics. 'Jigsaw' is a tool used by the US Air Force to streamline the planning of in-flight refueling. It is said that Jigsaw saved $12 million in fuel costs in the first month, approximately 2% of the entire DoD fuel budget.[21]

AI and machine learning have great potential to enhance Command and Control (C2) by providing faster and higher quality information. Smarter local processing algorithms can more easily identify data that is of interest, and they can save transmission of large data sets. The details of these types of systems are not often available in open publications. One area in which in AI and machine learning is mentioned is within logistics where enhanced processing is likely to reduce error rates (for example sending the wrong item), provide enhance operational tempo (as the system can make decisions more quickly) and reduce costs[22].

What are the differences between Commercial/Industrial Automation and Military Automation?

One of the main differences between civilian and military systems is the predictability of the environment. Military standard equipment has always needed to be able to operate in a very broad range of temperatures; weather conditions can vary substantially. A Canadian Study identified that Unmanned Aerial Vehicles (UAVs) had the potential to save around 50% of the hourly cost of running the air platform. However, they did not provide an all-weather capability and so the UAV could not fully replace the existing manned platform.[23] Civilian systems are developed and tested in predictable and relatively stable environments whereas military tasks are performed in unpredictable environments where the systems need to react to changes in weather, visibility, and levels of hostility. EHang has been awarded the certificate of AS9110D International Aerospace & Aviation Quality Management System Standard. To achieve this EHang's Autonomous Aerial Vehicles (AAV's) have passed the tests of durability, reliability, anti-interference, high/low temperature, high humidity, salt-spray, typhoon, and rainstorm. Civilian systems are advancing, and the evidence suggests that, where it is commercially advantageous, it is likely that civilian systems will be capable of operating in more challenging ranges of weather and temperature conditions. This should provide off the shelf systems that are closer to the needs of military customers.

As current AI and autonomous technology matures, it is easy to imagine that in the future autonomous aerial vehicles will be used extensively in the battlefield. They can fly at extremely low altitudes, below radar, and may be used to deliver supplies to the front line – an extremely perilous task. Removal of humans from front line activity could save many lives. While there is limited data in the public domain, the 2010 data for Deaths in Service shows that 95 deaths were as a result of hostile action.[24] It should be possible to reduce this figure, so during military operations a resupply system might be expected to save a significant proportion of ~100 annual deaths. In 2017, the UK Defence Science & Technology Laboratory (Dstl) started a programme named 'autonomous last mile resupply' to identify systems that could transport ammunition, rations and fuel over a distance of 30km.[25] The success of EHang AAV's shows that technologically capable systems to supply the front line may be available in the near-term.

The Levels of Automation

To fully evaluate the benefits and drawbacks of utilising automation in defence air and space systems, it is important to distinguish between the various stages and levels of sophistication involved in automated systems. This is referred to as the 'automation spectrum', a way to categorise a system using a scale from 0 to 5.[26] Table 1 outlines the categories.

The scale in Table 1 is useful in determining the extent to which automation and AI are used in the defence industry. Civilian world research is directed towards the most advanced and self-sufficient forms of technology possible, because this is where the best financial returns are. For military systems the battlefield is a difficult environment and the complexities are physical (eg hostile fire) and political (eg decision making when there are significant collateral damage implications). Therefore, it may not be possible in the near-term to aim to develop many military systems at level 5. From a technology point of view the systems are currently immature. It would only be sensible to aim towards high levels of automation when the technology has been enhanced and proved in representative environments. Legislation will also have an impact on this, particularly as the UK government has emphasised that weapons will always be under human control.[27]

Comparing military and civilian systems, there are a limited number of 'unusual phenomena' which could occur on a car journey, particularly on a motorway, as compared with 'green lane' driving. These can be well documented and considerable data gathered to test candidate 'self-drive' cars. This highlights that aiming towards high levels of automation for civilian systems is easier. The extremely unpredictable nature of conflict means that it is much more difficult to design and test military systems. So civilian systems will be likely to move into the upper levels of automation before military systems. The amount of investment in a system will also impact on the level of automation that is possible. The impact of the recent UK Government white paper should be that military systems can advance further in automation level.

Level 0	Constitutes no automation, entirely conducted by human processes and decision making.
Level 1	Involves basic task processing with preset constraints and instructions, could be referred to as a robotic process. An example may be a robotic arm for drilling holes in a manufacturing production line, or simple algorithm to speed data entry on a spreadsheet.
Level 2	This is sometimes referred to as 'enhanced process automation' where a system can make decisions and execute processes but will refer any difficult decisions to a human. An example could be a chat-bot customer service aid: in the event that it cannot resolve an issue, it will refer its case to a human.
Level 3	Semi-autonomous: systems can make decisions and execute tasks whilst continuously learning from experience. However, occasional human intervention is needed for low probability events. An example is a self-driving car in which the driver can safely divert attention away from any driving tasks but will be notified if there is a need for human intervention.
Level 4	Automation at a stage where a system is completely capable of running itself with no intervention required unless it faces an extreme case or environment. An example would be a car in which the driver can safely sleep and only be required to intervene in an unlikely situation, for example no GPS coverage.
Level 5	Full automation which never requires any human intervention. An example may be an electric surveillance drone which recharges itself, continuously learns and improves, and analyses any data internally to decide how to react before ultimately doing so.

Table 1: Levels of Automation

Where are the Risks from AI and Automation?

Human operators make mistakes and automated systems can also behave unexpectedly, particularly in a complex environment where their training data is sparse. This will lead to concern about using such systems, which may hold back their development if this is not managed carefully.

Despite the risks, the use of Automation and AI have a place within the battlefield. Automation and AI are becoming increasingly capable and potentially better than humans when it comes to long range identification because robots do not need to protect themselves in cases of low certainty of target identification; they can move closer to the enemy and be self-sacrificing if needed. Ron Arkin, a professor of robotics at Georgia Institute of Technology once said 'it is a thesis of my ongoing research for the U.S. Army that robots not only can be better than soldiers in conducting warfare in certain circumstances, but they also can be more humane in the battlefield than humans'.[28] Ultimately, extreme technological advancements naturally come with teething problems, although these are often grave when used in conflict. Foresight into the long-term capability of these systems should be taken into account when assessing their viability.

It is difficult to envisage a time when there will not be human control over lethal weapons in any civilised society. But control might take place at a different point within a decision-making chain. So, this would maybe involve having human authorisation for 'a possible firing' rather than actually pulling a trigger. The system may then need to perform final checks around collateral damage.

Autonomous weapons have been deployed for more than two decades. One early fratricide case was when a US Army Patriot air defence system shot down a British Tornado in Iraq in 2003. The Defense Science Board publicly commented that Patriot system was over-deployed, there was a communications failure meaning that the British aircraft was not identified as friendly, but there were also said to be issues with the Patriot operating philosophy and protocol. This incident highlights the need for careful implementation and increased training for the operators of these weapons. Extended periods of success with autonomous systems lead to complacency in their usage, so such a system should be treated with great prudence.[29] After all, AI consists of computer-based algorithms, which by nature have a black and white understanding of their environment and can be unpredictable when faced with ambiguity.[30]

While there are difficulties in moving human control from a trigger to an enabler, allowing a lethal system to fire itself under certain conditions, it may be wrong to conclude that this is far too risky. There may be a time when it would be sensible to allow more of a nation's lethal systems to make 'fire/don't fire' decisions. This is because there are considerable risks from not automating. Adversaries have always been good at spotting weakness in a military system and they will exploit this. In the commercial world speed of response has become an important competitive advantage. Financial traders and warehouses are using technology to speed up their operational activities. What if adversaries took the same approach? What if the UK was forced to respond quickly to complex situations in which both 'no response' and 'the wrong response' led into an escalating conflict, perhaps as a result of having to rapidly classify certain threats within a swarm as hostile? In this and many similar situations AI is an essential enabler.

What is the direction for the future for Air and Space and what is the Gap Between the Possible and Acceptable?

Automation in the commercial world is progressing very quickly. Even with logistic companies, like Ocado, investing heavily in robotic systems that remove labour and time from warehouses, they are not, at present, implementing fully autonomous delivery vehicles in the near-term to save the cost of a driver, despite trialing vehicle technology from Oxbotica. This is a more complicated problem.

So, within the military some sections of the battlespace may be able to be fully automated. But taking this to an extreme, and having fully automated decision making for lethal systems, is not legally allowed in the UK so this will certainly not be possible in the near future. Only if there were to be changes in legislation could the opportunities expand.

It will be possible to adapt a number of existing commercial systems to operate in the climate range of military systems. However, the complexity range is more challenging and is likely to take time. The military market is smaller than the civilian market for many automated systems and so the complexity of the defence industry along with a smaller margin for error, will mean that progress will be slower in defence. The commercial companies will not see defence as the highest priority customer.

The 'art of the possible' may be to draw rapidly on commercial technology and automate military systems to lower levels of automation than their commercial counterparts. The aim may be to go further over time when additional training and test data can be gathered and evidence about safety accumulated. There will always be a need to develop more capable systems and have them available so that they have been trained and tested. These systems can be brought into service when needed.[31] There is certainly a need to have automated systems that can provide rapid and appropriate defence. A 'minimum viable system' is the smallest and simplest system able to support any market-shaping vision. It will be important to understand what is the minimum viable system for each potential automation application, how can these systems be developed in parallel with existing commercial capability and how could they be used if they were really needed?

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