ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

Growing the Commercial Drone Industry in Ontario

Growing the Commercial Drone Industry in Ontario

About OSPE

The Ontario Society of Professional Engineers (OSPE) is the voice of the engineering profession in Ontario. We represent the entire engineering community, including professional engineers, engineering graduates and students who work or will work in several of the most strategic and influential sectors of Ontario's economy.

OSPE elevates the profile of the profession by advocating to government, offering valued member services, and providing opportunities for ongoing learning, networking, and community building.

Contributions

This report was commissioned by OSPE's Research and Innovation Task Force. The purpose of this task force is to inspire and drive engagement between engineers and civil society, to solve complex societal issues through research and innovation.

A special thank you to:

Laura Yu, P. Eng., OSPE Board Member
Emanuel Corthay, P.Eng., OSPE Member
Jeremy Chan- Hao Wang, EIT, OSPE Member
Eric Blaise, Ph.D., M.Eng., OSPE Member

Author
Samuel Looper

Samuel is an engineering student currently completing a major in Robotics at the University of Toronto. He is passionate about both technology and policy and dedicated to leveraging emerging technologies to bring tangible benefit to our communities. He is developing expertise in robotics and computer vision technology development, and is actively engaged in policy advocacy, authoring policy research papers that were published by the International Astronautical Federation and the Canadian Science Policy Center. He is the Executive Director of the University of Toronto Aerospace Team, the schools largest student design team with a focus on technical and leadership skills development, and is completing an internship at the UAS Center of Excellence, Canada's most advanced drone testing facility and commercial drone technology cluster based in Alma, Quebec.

Acknowledgement

We would also like to acknowledge the numerous people that have contributed to this document in the form of review, informal input or through structured interviews. We would like to mention Ian Fejtek, P.Eng., from Bombardier, Marlene Conway Diels from the Consortium for Aerospace Research and Innovation in Canada, Jeremy Laliberte, P.Eng., from Carleton University Aerospace, Jonathan Hack, P.Eng., from Centennial College, and Jeremy Wang, EIT, from Ribbit.

Growing the Commercial Drone Industry in Ontario

Contents

Growing the Commercial Drone Industry in Ontario

Executive Summary

Ontario has an opportunity to become a leader in the development of Remotely Piloted Aircraft Systems (RPAS), or drones, as it grows into a multibillion-dollar industry worldwide. At the intersection of aerospace and robotics, RPAS technology presents a cost effective and increasingly automated solution, to collect data from the skies. Today, drones are synonymous with either recreational use or their use in the defence sector. However, advances in sensors, computing hardware, artificial intelligence, and communications technology are significantly increasing the capability of RPAS and the value of the data they collect. As the technology matures, the growth of the RPAS industry will be driven by new applications in the commercial and civil sectors.

Ontario's economy stands to gain significantly from the deployment of these technologies in a wide range of industries including agriculture, energy, insurance, and entertainment. As Canada's largest economy, Ontario has the potential to be one of the largest end-user markets of RPAS technology. Ontario also has a strong research and development ecosystem and is world leader in key industries such as aerospace, advanced manufacturing, and Information and Communications Technology (ICT). This creates an ideal environment for the development of the RPAS industry into a significant driver of job growth and productivity for Ontario.

Currently, the RPAS industry is composed of small businesses and startups that face unique challenges when growing and scaling their operations. To mitigate safety risks on the ground and in the air, there are significant regulatory barriers to operating drones. Substantial investments are required for businesses to train personnel, ensure operational safety, and validate the safety and reliability of their technology. In addition, there are gaps in the capabilities of these small businesses, and a lack of awareness regarding commercially viable applications of RPAS. As such, drones have not yet been widely adopted in many industries where these technologies could provide significant value.

This report presents an overview of the key issues regarding RPAS and proposes several recommendations for a provincial policy regarding these technologies. These recommendations focus on promoting the adoption of RPAS in commercial and civil sectors, funding the development of new business models using RPAS technology, and working with all levels of government to create a regulatory environment that promotes safety and innovation. With an effective policy response to this emerging technology, Ontario can create jobs, grow the economy, and adapt our industries to the 21st century.

Growing the Commercial Drone Industry in Ontario

1.Introduction & Methodology

With a strong academic ecosystem, well-established technology industries, and highly qualified workforce, Ontario has an opportunity to place itself at the forefront of the emerging Remotely Piloted Aircraft Systems (RPAS) industry. RPAs, also known as drones, have existed for decades as a technology reserved for security and defence or as toys for hobbyists. Today, they are enabling businesses to capture critical data, and providing services ranging from search and rescue to last-mile delivery and infrastructure inspection. The Ontario Society for Professional Engineers' (OSPE) Research & Innovation Taskforce presents the following report to provide an overview of the current state of the RPAS industry and outline some key recommendations for policymakers to ensure its growth in Ontario.

The Research & Innovation Task Force has engaged with stakeholders across the RPAS industry and conducted independent research to serve as the basis for this report and its resulting recommendations. The task force conducted over 15 interviews across the following categories of stakeholders:

1. Industry
    a. Established RPAS Manufacturer or Service Provider
    b. RPAS Technology Start-Up
    c. RPAS Technology End-User
2. Government
    a. Regulators
    b. Economic Development Agency
    c. RPAS Technology End-User
3. Academia
    a. Research Institution or Agency Engaged in RPAS Technology

The interviews followed a semi-structured methodology, serving as both primary research and to solicit input on key issues related to policy in each respective stakeholder category.

Secondary research was conducted to supplement the input from stakeholders. This included a literature review of emerging RPAS technologies, analysis of economic data related to industries with strong RPAS service use cases, research on current RPAS technology companies (startups and established), and an analysis of the current Canadian RPAS regulatory framework. Lastly, a survey was conducted of best practices related to RPAS research and development, commercialization investment, and regulation in key international markets.

This report builds on the findings and industry feedback from a previous report from the Ontario Society of Professional Engineers, entitled Growing the Drone Industry in Ontario, published in March 2020 [1].

2.RPAS Technology

2.1 Technology Overview

Remotely Piloted Aircraft Systems (RPAS), also known as drones, represent a significant paradigm shift in the development of aircraft and the use of our nation's airspace. While the basic technology of teleoperated flying devices has existed since the early 20th century [2], several advances in electronic hardware, robotics software, and data analysis have enabled the drones we see today. Removing the need for an onboard pilot, RPAS can be built in a much smaller form factor and be dedicated to carrying payload. Such payloads include instruments to collect data, end effectors to perform a task or cargo to transport between locations.

Multi-rotor RPAS can be used to tightly navigate around infrastructure or remain stationary for the purpose of data collection, while fixed wing RPAS can collect data or transport goods over large distances. In both cases, the typical critical systems for a RPAS include the aircraft, its propulsion system, a flight controller to automate the control of the aircraft, a suite of flight sensors (GPS, altimeter and Inertial Measurement Unit [IMU], among others), a communications link to transfer data and send command & control (C2) instructions, and a Ground Control System for the remote pilot [3]. Together, these systems enable a novel class of aircraft able to collect valuable data and operate without any crew on board.

Other relevant technological developments include advances in hardware, software, and data analysis. The process of collecting, managing & analyzing large quantities of data, or Big Data, is the cornerstone of most promising commercial applications. Geographical Information Systems (GIS) and other software tools enable RPAS users to extract useful information and actionable insights from data [4]. Advances in artificial intelligence (AI) have led to tremendous improvements in the effectiveness of tools and analyses that leverage big data. As such, RPAS and the development of AI technologies are inextricably linked. The advent of AI has been driven by improvements in computer hardware, notably the advent of the Graphics Processing Unit (GPU), as well as new machine learning techniques such as Deep Neural Networks (DNN). Today, organizations can deploy highly accurate and effective software solutions to automate image processing, object recognition and many other tasks [5]. Artificial intelligence is also being leveraged to process onboard data in real time and improve the safety and reliability of autonomous operations through onboard path planning, object detection and collision avoidance [6].

2.2 Benefits & Impact of RPAS Technology

The development of RPAS presents a significant market opportunity due to their unique value proposition. RPAS allow for the automation of aerial operations, while drastically reducing the required weight and complexity of aircraft by removing onboard crew. This can significantly reduce the cost of an aerial operation and enable new commercial services that would have previously been unprofitable. In addition, coupled with advances in sensors such as cameras and LiDAR, and the development of robust data analysis methods and AI, these new operations can provide data only obtainable from the sky, and leverage that data to provide value to a customer.

In 2016 over 110,000 drones were sold for commercial use, and the commercial drone technology and service industry was valued at $6.6 billion USD globally [6]. Goldman Sachs research estimates that by 2020 the commercial drone industry grew to over $13 billion worldwide [7]. While currently Canada does not rank in the top markets for this emerging industry, there is major untapped potential in providing services for industries such as agriculture, natural resources, infrastructure and utilities, construction and heavy industry, as well as a host of others such as insurance, media, and public safety.

2.3 Integration of RPAS in the National Airspace

While there are significant commercial applications today, the true potential of autonomous aircraft will only be unlocked when they are fully integrated into the national airspace. Under Canada's current regulatory framework, flying a drone within line of sight, at low altitude, and away from people is simple and accessible for commercial operators. There are significant safety risks, and corresponding technical challenges, in enabling flight beyond visual line of sight (BVLOS), overpopulated areas and in controlled airspace [8]. Ensuring that commercial operators can meet the requisite safety standards to routinely fly these complex flight missions is a prerequisite to some of the most promising applications of RPAS, including drone delivery, infrastructure inspection over large distances, and RPAS operations in urban environments.

In recent months, Transport Canada has published two reports which provide a preliminary strategy and timeline for the integration of RPAS in the national airspace. Firstly, they will be building on their current RPAS Safety Assurance standard to ensure aircraft, subsystem, and payload manufacturers have a well-established airworthiness standard to meet, for their technology to be deployed over people in highly automated systems. Next, they will be developing operator certification and pilot operational level ratings for BVLOS operations and operations with aircraft with a takeoff weight above 25kg. This will provide commercial operators with a clear and standardized path forward to deploying heavier aircraft, or long-range operations outside of the reach of a single pilot [8]. These operations unlock new commercial opportunities by greatly expanding the reach and scale of RPAS operations.

Finally, Transport Canada has developed a roadmap for the development of the technology and infrastructure necessary for integrating RPAS into the national airspace [9]. The core technologies required for this realignment of Canadian airspace are remote identification, detect and avoid (for remote collision avoidance), and Remote Traffic Management (RTM), which includes flight preparation, surveillance/tracking, contingency management, conflict management, and communications. These technologies will be built around a central service provided by Nav Canada, the federal agency in charge of air traffic management. Industry stakeholders and commercial service providers will be engaged through a series of RTM service trials. These will ensure commercial services can be developed to meet the needs of the new Canadian airspace, as services will be validated at a small scale before being gradually deployed. The timeline for the development of Canada's RTM infrastructure will happen in parallel with Transport Canada's proposed regulations, allowing for a gradual increase in authorization for complex operations while ensuring safety standards are met.

Overall, this represents a tremendous opportunity for the RPAS industry in Ontario. Canada finally has a clear path towards autonomous aircraft operating at scale, and these developments should be leveraged to grow the drone industry in the province. Similar efforts are happening around the world, notably with the Federal Aviation Administration in the United States. It is imperative that Ontario capitalize on this opportunity and become a leader in RPAS technology.

2.4 Emerging Technologies & Trends

Several new technologies are currently in development to solve key challenges in the safe integration of RPAS and increase the commercial value of RPAS services for end-users. As mentioned in the previous sections, many countries are developing centralized RTM systems. Advancements in Information and Communications Technology (ICT) will be critical to the future of RTM. The advent of the 5G communications standard will be critical in providing a high bandwidth, secure and reliable backbone for RTM with sufficient network coverage to service all RPAS end-users [10]. Specialized communications infrastructure, protocols, and hardware will be required to securely transmit flight plans, telemetry, warnings and other aeronautical information between remotely piloted aircraft, RTM service providers and other stakeholders. Finally, new software systems will be required for automated RTM functionalities (flight planning, dynamic rerouting and geofencing) and to provide user interfaces to enable pilots and other end-users to effectively interact with RTM [9].

Many industry stakeholders are also pushing for the widespread adoption of remote identification [11]. Remote identification is the ability of an RPAS to wirelessly communicate identification information for authorized parties to validate, which will serve to ensure all RPAS operating in the national airspace are authorized and are following proper regulations.

In addition, the challenge of managing potential conflicts between remotely piloted aircraft will need to be addressed with technological solutions. Detect and Avoid (DAA) systems will utilize either onboard or ground based sensors to detect other aircraft and execute an avoidance maneuver in a conflict scenario [12]. The leading technical approaches include electro optical and radar sensors to detect intruder aircraft. For uncooperative or rogue RPAS, counter-drone systems are being developed to disable dangerous aircraft either by kinetic means or by radio frequency (RF) interference [13].

Finally, several technological advances will add value to commercial RPAS by improving the scale and quality of existing services or enabling new RPAS operations. BVLOS flight will require improved communications systems for Command and Control (C2) links [10]. RPAS operations will also be facilitated by improvements to remote pilot interfaces. New developments in AI and aerial robotics will enable a gradual automation of flight operations. This includes developing new robust flight control algorithms and using computer vision to guide precision takeoff and landing [14]. AI will also be deployed further down the value chain for the analysis and processing of the data captured by RPAS [15]. The field of machine learning is an active area of research which has yielded significant improvements in complex tasks such as object detection and tracking. These technologies will be integrated into RPAS commercial services to increase the value and utility of the data and services provided by drones.

3.The RPAS Industry Today

3.1 Key Stakeholders

RPAS Operators
RPAS operators include all businesses, departments or teams within businesses, non-profits or government agencies that operate RPAS for civil or commercial purposes. Most of this segment is comprised of small businesses with less than 20 employees and includes several start-ups or new businesses. These businesses are driving the emerging RPAS industry by providing value to customers through commercial RPAS services, generating revenue from the use of RPAS, and creating demand for RPAS technologies.

RPAS Platform and Equipment Manufacturers
RPAS platform and equipment manufacturers include businesses that develop, manufacture, and integrate drone systems. While demand for these systems has typically been driven by the defence industry or hobbyists, today new systems are being developed specifically for commercial operations. These companies supply RPAS operators with the technology that enables their commercial services and can generate export revenue by selling technologies to clients outside of Ontario.

RPAS Commercial Service Customers
This broad category represents current or future end-users of RPAS technology and RPAS commercial services. These companies are vital to the future of the Canadian RPAS industry as they drive the demand for new technologies and services.

Adjacent Industries and Service Providers
Ontario's strong technology and innovation industry provides an ideal ecosystem for the emerging RPAS industry. Ontario is an established hub for the aerospace and ICT sectors. These industries provide infrastructure, training, personnel, funding for relevant research and development (R&D), and new technologies that are vital to RPAS operations.

Government
All three levels of government are important stakeholders in the RPAS industry. The federal government has the mandate of regulating the use of Canada's airspace through Transport Canada. All three levels of government also provide funding for R&D and to small businesses which contribute to the design and development of these technologies.

Academia
Research institutes across the province contribute to the RPAS industry by partnering with industry for R&D and developing new technologies. Universities and colleges also help train the province's pool of highly qualified professionals like engineers for emerging industries such as RPAS commercial services.

3.2 Industry & Innovation in Ontario

Ontario is the largest and one of the most diversified economies in Canada, with several industries and institutions that will fuel the growth of RPAS technology in the province. Some of the key industries outlined by the Ministry of Economic Development, Job Creation and Trade include aerospace, automotive and advanced manufacturing, information and communications technology, and energy.

The aerospace industry contributes over $5.3 billion to our GDP (direct and indirect), and Ontario accounts for 28% of the industry in Canada [16]. Ontario attracts over half of the world's top global aerospace corporations such as Airbus, Bombardier, United Technologies, Safran, Mitsubishi Heavy Industries, and others.

These corporations are attracted by a highly skilled workforce, a diverse and established supply chain, and the research expertise of academic institutions such as the University of Toronto, Ryerson University, and Carleton University. The success of aerospace has a markedly positive effect on the province, creating over 22,000 jobs, and annual research and development (R&D) spending of over $500 million [16].

Ontario has developed into an international hub in several fields such as landing gear, business jet aircraft, and avionics systems [16]. The growth of the aerospace industry in the province will be predicated on leveraging current R&D to create new areas of expertise in emerging technologies. The aerospace sector benefits the RPAS industry as the province already has a strong pool of highly qualified personnel, a well-established aerospace research ecosystem, and multinational corporations investing in research and development.

Ontario is home to the second largest IT market in North America, with hubs in Waterloo, Toronto, and Ottawa. This industry accounts for over $41 billion in GDP, and over $3 billion in R&D investment. Ontario has leading higher education institutes, creating over 42,000 graduates in science, technology, engineering, and math (STEM). The growth of this sector has led to Ontario developing expertise in fields relevant to RPAS such as AI, data analytics, Internet of Things (IoT), and telecommunications [17].

Another key component of the Ontario economy is advanced manufacturing. This is primarily driven by the automotive sector, which includes five auto assembly plants and over 700 parts suppliers across the province. This has led to significant R&D spending in fields such as robotics, and Ontario also includes the greatest concentration of robotics companies in Canada [18]. As research institutes and private industry invest in robotics and automation, these technologies can be applied to deliver automated services and develop mechatronic payloads for RPAS.

3.3 Ontario RPAS Manufacturers and Service Providers

Today, the RPAS industry represents a niche mostly composed of small businesses and startups. These companies have significant growth potential, and the industry is poised to grow over the coming years. There are 8 member companies of the Ontario Aerospace Council that provide RPAS technology or services [16]. Unmanned Systems Canada, an organization representing the RPAS industry across Canada, has 31 RPAS

manufacturers and service providers from Ontario. Of these, 8 design and manufacture their own RPAS platform. Of the 20 RPAS service providers in Ontario, most are focused on mining, agriculture, infrastructure, and film sectors. Finally, another significant area of focus for the Ontario RPAS industry is the integration of RPAS in populated areas. This includes RTM and other technologies to reduce ground risks such as RPAS parachute systems [19].

Most of these companies are small businesses with less than 20 employees, and nearly a third have been founded in the last 5 years. Many of Ontario's drone companies are alumni of startup accelerators such as Communitech, Ryerson DMZ and the Creative Destruction Lab. While this indicates strong growth for the RPAS industry, startups and small enterprises face unique challenges to scaling and commercializing RPAS technology.

Despite the sizable market opportunities, the highly developed aerospace sector, and a history of past success, the RPAS industry in Canada, and Ontario specifically has not yet established itself as a market leader relative to other major hubs in the United States, France and Israel among others. This is primarily due to a lack of R&D, commercialization, and regulatory supports—recommendations for which are given in Section 5. For reference, the United States drone manufacturing industry reported over $4.7 billion in revenue in 2019, with large multinational companies such as Northrop Grumman, General Atomics, Boeing, Textron and Aerovironment making up most of the market share [20].

The US market is driven primarily by defence spending, however other significant markets such as China and France are driven by a growing consumer market as evidenced by the success of companies such as DJI, Yuneec and Parrot. In addition, local market demand plays a significant role in growing the industry. Below is a table of the largest markets in terms of commercialized UAS platforms, and a table of largest markets estimated drone spending in USD. As such, leveraging defence procurement and growing the demand for UAS technologies in the Canadian commercial and consumer markets is critical to enabling a sustainable drone manufacturing industry.

Largest Global Markets (Demand)			Largest Global Markets (Supply)		
#	Country	Estimated Drone Spending (USD)	#	Country	Commercialized Drone Platforms
1	United States	$17.5 billion	1	United States	628
2	China	$4.5 billion	2	China	309
3	Russia	$3.9 billion	3	France	114
4	United Kingdom	$3.5 billion	4	Russia	99
5	Australia	$3.1 billion	5	Germany	88
6	France	$2.5 billion	6	United Kindom	84

Table 1: Largest global drone manufacturing markets by estimated drone spending (left) [7] and largest global drone markets by number of commercialized drone platforms (right) [21]

4. The Economic Impact of RPAS in Ontario

RPAS technologies are poised to have a large impact on Ontario's economy. This technology has the potential to disrupt business practices across many sectors. The fundamental value proposition of RPAS is that it enables businesses to autonomously collect data and conduct tasks in a more reliable and effective way. Drones have already been successfully deployed to provide value to customers in several industries. However, RPAS technologies and services have not yet been widely adopted in most sectors.

As the industry grows and business models are successfully implemented to generate revenue from the commercial use of RPAS, the economy of Ontario will significantly benefit. The potential applications and use cases for RPAS vary by industry, leading to different technical or operational requirements. Each potential client industry has their own value proposition and existing level of adoption. Nonetheless, across the province's most valuable economic sectors, RPAS will enable companies to operate more safely, efficiently, and at a lower cost. This will lead to new businesses specializing in RPAS operations and existing businesses utilizing RPAS technologies in their day to day operations themselves. These new services will create jobs and generate new revenue for the RPAS sector while making Ontario's economy more competitive and productive.

4.1 RPAS Technology and Canadian Industries

Canada has a modern and diverse economy, benefitting both from a wealth of natural resources and a strong knowledge economy. This section will analyze 5 of the largest sectors of the Canadian economy and the potential for commercial RPAS operations in those industries. This section does not include some of the most promising areas of application for RPAS in Ontario. These remaining sectors will be discussed in section 4.2.

4.1.1 Real Estate
Share of Canadian GDP: 13.01%
Value of the industry in Canada: $227 billion CAD
Key applications of RPAS: Aerial photography, building inspection

Canada's most valuable industry is real estate. Property values have seen significant increases over the last 10 years, driven by the growth of demand in urban areas such as Toronto and Vancouver [20]. Last year, real estate brokers earned over $15 billion in revenue, increasing by more than 8% [21]. In terms of RPAS services, aerial real estate photography was one the earliest and most profitable businesses enabled by this emerging technology [22]. Aerial photography was previously reserved for only the most expensive properties, requiring a manned helicopter. Today, drones can take unique, high quality footage to showcase a property. Real estate aerial photography using RPAS requires only basic technology and operational capabilities. Affordable off-the-shelf RPAS systems can be purchased for less than $500 and flown by anyone with a basic RPAS pilot license. Drones are already widely adopted in real estate today, serving as a model for the successful integration of drone technology in a key sector of the Canadian industry. Furthermore, the growth of the real estate market is driving demand for related RPAS services such as building inspections and site surveys for construction.

4.1.2 Finance and Insurance
Share of Canadian GDP: 7.07%
Value of the industry in Canada: $123 billion CAD
Key applications of RPAS: Risk Assessment, Fraud Prevention

Another key pillar of the Canadian service sector is finance and insurance, which is concentrated in the Toronto region, known as the financial capital of Canada. The Canadian insurance industry paid out over $39 billion in claims for property and casualty last year [23]. The process of monitoring and assessing risk is critical to the industry, as is effectively processing and verifying insurance claims. The ability of RPAS to collect data on assets

efficiently and in a cost-efficient manner could save the insurance industry worldwide over $6.8 billion per year, according to a study by PricewaterhouseCoopers (PwC) [24]. Drones can be used as a preventative measure to monitor risks to property or people or used to assess the damages during a natural disaster or accident. This could lead to significant savings for Canadian insurers by improving the accuracy of claims and detecting fraud. RPAS data can also be used to improve the assessment of risks, saving money for both the consumer and the insurer by allowing companies to better tailor prices for insurance services.

4.1.3 Construction
Share of Canadian GDP: 7.07%
Value of the industry in Canada: $123 billion CAD
Key applications of RPAS: Site Survey, Asset Monitoring, Maintenance, and Inspection

The construction industry is critical to the Canadian economy, employing over 1.3 million people and contributing over $123 billion CAD to the Canadian GDP [25]. RPAS have the potential to provide tremendous value, enabling safer, more efficient construction projects. Drones can be used in the pre-construction phase to survey potential sites, creating digital elevation models (DEMs) and other detailed data of a construction site [24]. This allows for better and more effective construction designs, while also leading to more accurate contract valuations. During a construction, RPAS can be used to collect data on the progress of a construction project, identify faults and discrepancies, and better evaluate when maintenance is required on a building. Finally, RPAS can monitor construction sites for safety risks and better evaluate environmental impact. While the application of RPAS technology in construction is in its infancy, there are numerous applications that can provide lucrative business opportunities for RPAS operators in this sector.

4.1.4 Oil and Gas

Share of Canadian GDP: 4.11%
Value of the industry in Canada: $72 billion CAD
Key applications of RPAS: Infrastructure Monitoring, Environmental Impact Assessment

Canada's oil and gas resources are some of the most valuable in the world, and RPAS technologies have the potential to reduce the financial and environmental costs of extracting and transporting them. Canada has over 840,000 km of pipelines transporting nearly 5 million barrels of oil every day [26]. Effective monitoring of this critical infrastructure can save companies billions and ensure they comply with strict environmental regulations [27]. RPAS are also being used to survey prospective areas for drilling operations. They can be used to monitor drilling rigs and refineries to ensure infrastructure is properly maintained and to evaluate the environmental impact of the operation. Finally, drones could be used to deliver critical components to offshore rigs or other remote drilling operations. The oil and gas sector represents a tremendous opportunity for RPAS technology but requires more advanced technology and complex operations. Many of these use cases will be particularly profitable if RPAS are operated autonomously or beyond visual line of sight.

4.1.5 Mining and Quarrying

Share of Canadian GDP: 4.10%
Value of the industry in Canada: $72 billion CAD
Key applications of RPAS: Risk Assessment, Fraud Prevention

Mining is a major industry in Canada, which is home to some of the world's largest deposits of metals, gemstones, coal, and potash [28]. Many mining operations are in remote locations, in either open-cast or underground sites [29]. RPAS can be used to survey vast territories, providing valuable geographical and hydrological data for the planning and design of mining operations. RPAS can also survey areas to assist in mining exploration. On an active mining site, RPAS can be leveraged to monitor and report progress of mining operations, while evaluating environmental risks [24]. Currently, most of these applications are confined to open-cast mines, but a significant amount of research into robotics in GPS-denied environments may lead to additional applications for RPAS in underground mines [30]. While RPAS operations for the mining industry involve difficult technical challenges, harsh conditions and remote environments, the adoption of RPAS technology in the mining industry could provide significant revenue to the drone industry in Canada.

4.2 Key Areas for RPAS Services in Ontario

While Canada's economy at large is sure to benefit from the integration of RPAS in several major sectors, Ontario's economy is uniquely positioned to benefit from RPAS. This section will provide an overview of some key verticals where RPAS could provide significant benefits to the economy of Ontario.

4.2.1 RPAS in Urban Areas

Ontario is home to the largest share of Canada's urban areas and population centers. These are mostly concentrated in Southern Ontario along the Highway 401 corridor. These include the Greater Toronto Area, Canada's largest metropolitan area, as well as Ottawa, Ottawa, Kingston, Kitchener, London, and Windsor [31]. There are areas of potential application for RPAS that are especially relevant in this context. This includes the use of RPAS in the utilities and waste management industries, where they can be used for site inspections and infrastructure monitoring.

Growing the Commercial Drone Industry in Ontario

Furthermore, Toronto's status as Canada's largest city makes it a hub for the telecommunications industry. Drones can be used to inspect cell towers, a costly and dangerous operation when done manually. Drones are also being used to improve the design of cellular networks by collecting data on line-of-sight and network coverages across large areas. Finally, tethered RPAS can be used to quickly provide temporary cellular network coverage during major public events or natural disasters [24].

RPAS can also benefit the public sector, as drones have been successfully deployed to support emergency services for accident reconstruction or security monitoring [39]. Finally, an oft-cited use case for drones is urban package delivery. The most relevant applications in this field involve last-mile transportation and the delivery of critical or time sensitive materials in fields such as healthcare, manufacturing, or auto repair [32].

For each of these applications, there are significant technical and regulatory barriers to the full integration of RPAS in population centers. Operating in urban environments involves significant risks to people and infrastructure, and often requires flying in controlled airspace which RPAS will share with manned aircraft. The regulatory requirements in terms of system reliability and operational safety will be proportionally higher, which will create a significant barrier to entry for RPAS service providers [33]. Nonetheless, as technology solutions are validated and operators develop the necessary procedures and systems to ensure the safety of their operations, there will be significant potential for new revenue generating services in Ontario's urban areas.

4.2.2 RPAS in Rural Areas

On the other hand, operations in rural areas may be an apt proving ground for several emerging technologies, as the risk to people and assets is significantly lower. Ontario has more farms than any other province in Canada, and agriculture is an area of significant interest for RPAS commercial applications. Drones can be used to perform several critical tasks from the air, from collecting data and monitoring crops to spraying pesticides or seeds [24]. This can reduce the cost of maintaining agricultural land while improving the quality and quantity of data collected. The use of aerial data for crop supervision, soil and field analyses, and crop health assessment has the potential to reduce the environmental impact of intensive farming practices while boosting crop yields for farming businesses of all sizes. Horticulture and viticulture are important subsectors of the agriculture industry in Ontario and are of great interest for RPAS technology applications. Precision agriculture is critical in these sectors due to the specific conditions required to grow grapes, berries, and other high value crops [35].

Forestry is another key application of RPAS in predominantly rural areas [24]. RPAS can be used to survey large swathes of territory to assess the density of vegetation, canopy height, and other key indicators for the value of forestry operations. They can be used to help plan and monitor the construction of roads and other critical infrastructure and monitor the progress of forestry operations. Finally, drones can be highly effective in performing visual impact assessments (VIA) of forestry operations, monitor forest health and regrowth, and other critical tasks to ensure forestry operations comply with environmental regulations and are conducted in a sustainable manner.

Finally, package delivery by drone is also particularly relevant in the rural context. Many rural and isolated communities have poorer access to healthcare and other public services, most notably indigenous communities across Ontario and the rest of Canada [36]. RPAS may provide a cost effective and flexible mode of transportation for areas that are hard to access or remote. Ontario RPAS service provider Drone Delivery Canada has run successful pilot projects with the Moose Cree First Nation and Georgina Island First Nation to provide logistic support using their drone delivery platform [37].

4.2.3 RPAS in the Energy Sector

In both urban and rural areas, RPAS have the potential to provide significant value to the energy sector of Ontario. Ontario's electricity generation is highly diversified, with natural gas, nuclear, hydro, wind, and solar energy being significant sources of energy for the province [38]. Ontario's urban areas drive significant energy demand, and the province consumes over 125 Terawatt Hours of energy in 2018 [39]. As such, the generation, transmission, and distribution of electricity requires significant amounts of infrastructure across the province. Key infrastructure includes nuclear power plants, hydroelectric dams, solar farms, wind turbines, transmission lines, transformers, and distribution lines. RPAS can be used to plan and survey for new infrastructure development, as well as monitor infrastructure in real time to prevent faults and outages [24].

4.2.4 RPAS in the Entertainment Industry

One of the first successful commercial uses of RPAS was for the entertainment and media industry. Drones can be used to capture unique and high-quality footage for film and television productions. The film industry is worth over $2 billion and creates 30,000 jobs in Toronto alone, which has grown into a hub for film and television production [40]. Several of Canada's largest television broadcast networks are also headquartered in the province, including the Canadian Broadcasting Corporation (CBC), Bell Media, Rogers Sports & Media, and Corus Entertainment. Toronto is also home to Canada's largest film studios including Pinewood Toronto Studios, as well as the world renown Toronto International Film Festival. Drones have grown into an integral part of the industry, and the technology is already widely adopted across film and television productions [41]. This industry is responsible for a large share of the RPAS technology demand today and will likely remain an important segment for RPAS commercial services in the coming years.

5.Growing & Supporting the RPAS Industry

5.1 Research & Development

Ontario benefits from a world class research ecosystem, with several leading academic institutions, a highly educated workforce, and significant public and private investment in research and development. Two of the most valuable organizations in the Ontario RPAS technology R&D ecosystem are Center for Aerial Robotics Research and Education (CARRE) at the University of Toronto [42] and the Uninhabited Aerial Systems Training, Innovation and Leadership Initiative (UTILI) at Carleton University [43]. These two organizations lead programs to promote multidisciplinary collaboration in the field of RPAS technology. Furthermore, Ontario is home to the Vector Institute, a world leading research organization in the field of AI [44].

Academic and industry lead research efforts receive strong government support at the federal and provincial levels. Government agencies such as the National Research Council (NRC) and National Science and Engineering Research Council (NSERC) conduct collaborative research projects and provide funding opportunities for academic research labs, such as the Collaborative Research and Training Experience (CREATE) grants that funds both the CARRE and UTILI programs [45].

The next key stakeholders in Ontario's RPAS R&D ecosystem are industry partners. Private industry is a key contributor to R&D funding and can serve as subject matter experts for specific end use ca ses, accelerating the commercialization of new technologies. One prominent example of industry engagement in R&D is the L5 facility in Ottawa, Ontario [47]. L5 is a testing facility for autonomous vehicles and aircraft in urban environments, which will be critical to the growth of the RPAS industry in Ontario. The facility has significant support from private industry through the Ontario Centers of Excellence (OCE) and has partnered with local RPAS service providers.

5.1.1 Policy Recommendations

Effective government support is crucial to sustained research and development efforts for RPAS technologies. While OCE programs target public private partnerships for key industries such as autonomous vehicles and 5G, there are no R&D programs in Ontario specifically for the RPAS industry. Government agencies promoting R&D need to do more to address key challenges for the RPAS industry such as the uncertain and demanding regulatory environment and high levels of capital investment required for R&D.

The academic community should also align research objectives with the most relevant commercial use cases for RPAS technology. Ontario should follow the blueprint of programs such as UTILI to promote a multidisciplinary approach to RPAS R&D, focusing on applications with strong commercial value propositions, such as those outlined in section 4.2 of this report.

While traditional aerospace research focuses on aircraft hardware, a large part of the value of automated aircraft systems comes from software and data analytics. Ontario should leverage its expertise in ICT and artificial intelligence to become a leader in RPAS software and data analytics, and the development of these technologies should be better supported by R&D funding initiatives.

Ontario should also focus on specific niches such as RPAS in urban environments, remote traffic management, and RPAS for winter conditions in its R&D efforts. Any efforts by the Ontario provincial government and Ontario Centers of Excellence should also look to complement existing federal R&D programs such as NSERC and Mitacs, and should ensure the active participation of Ontario businesses in Transport Canada's RTM Service Trial program.

5.2 Commercialization

The commercialization of RPAS technology is the essential bridge between RPAS technology R&D and the growth of the RPAS industry in Ontario. As outlined in section 3, this emerging industry is mostly composed of small to medium businesses and startups. This indicates a strong potential for future growth but leads to significant challenges in developing new capabilities and scaling to enable new business models.

As such, Ontario has not yet fully capitalized on the potential for RPAS technology to create new business models and commercial services. There exists a fundamental gap between current RPAS service providers and potential industry end users, as only a small minority of businesses have adopted RPAS technology in sectors with promising commercial applications. This is partially due to a lack of awareness in potential client industries of the capacities of drone technology and the value proposition for specific drone services. This gap could be addressed by dedicated conferences or events that are organized or sponsored by the Ontario government. Technology adoption requires significant investment and organizational change, and businesses must be presented with a solid business case before integrating new technologies such as RPAS in their regular operations.

On the other hand, a gap exists between the technical capabilities of RPAS service providers and the needs of end users. Several commercial use cases require drones with heavier payload capacities and longer ranges than currently available. The standard for system reliability and safety assurance for RPAS is extremely high, akin to that of manned aviation, due to the significant safety and technical risk of aerial operations. RPAS service providers must continually make significant capital investments to develop the required technical capabilities, validate the reliability and performance of their technology, as well as develop the processes and systems to ensure the safety of their operations such as a Safety Management System (SMS) and Standard Operating Procedures (SOPs). To help small businesses, tackle these challenges, government led efforts have and will continue to be critical in enabling RPAS technology commercialization.

Growing the Commercial Drone Industry in Ontario

Ontario has successfully created a startup ecosystem that promotes the development of new tech-enabled enterprises. The Toronto and Waterloo tech startup scenes have emerged as some of the most dynamic and promising in North America [48]. Large incubators such as the Creative Destructive Lab, Ryerson DMZ, and Communitech, receive government support [49], enabling them to foster new promising startups in the field of RPAS such as Vertical AI, DreamQii, AirMatrix, and Avidrone. Many Ontario startups have been financed by government or industry grants such as OCE's SmartStart Seed funding [50].

Since 2013, Ontario venture capital firms have invested over $9.9 billion in startups and small businesses, representing 43% of venture capital in investment in Canada [52]. Nonetheless, Ontario's investment in venture capital relative to GDP lags behind the United States and Quebec [53]. Furthermore, these investments are concentrated in industries such as ICT, life sciences, and cleantech, representing 90% of all venture capital investments last year [52]. As such, alternate sources of funding are necessary to bridge the gap in financing for RPAS businesses.

Currently, there are several government assisted programs available to help RPAS businesses commercialize new technologies. Government agencies and industry led nonprofits have developed programs such as the Alliance Grants and Engage Grants for university and colleges (NSERC) [54], Mitacs [56], and the Ontario Centers of Excellence (OCE) Vouchers for Innovation and Productivity [57] to support public private partnerships for technology commercialization. These programs successfully utilize cost sharing agreements to reduce the financial burden of R&D on industry partners, with some programs structured specifically to support SMEs.

The Downsview Aerospace Innovation and Research (DAIR) Hub was established in 2019 to serve as a cluster of expertise for aerospace [58]. The industrial development will include campuses for three universities, the Centennial College Center for Aerospace and Aviation, and R&D facilities for several of Ontario's major aerospace companies. This new initiative will promote technology transfer and will enable the commercialization of technologies through partnerships between academia and industry.

Furthermore, industry led organizations also play an important role in promoting the development of new commercial RPAS services. Unmanned Systems Canada (USC) is a non-profit organization representing the Canadian RPAS industry and has several existing programs to promote collaborative efforts to grow the industry [59]. They host networking events, forums, and conferences, notably to gather industry feedback on federal RPAS regulations.

The Ontario government and civil sector can play a leading role in RPAS commercialization by promoting their use within ministries and government agencies. Applying RPAS technologies to critical government functions such as surveys, inspections, and policing can improve the quality of government services while saving taxpayer dollars. There have been several instances of successful RPAS operations in the civil sector such as with the Ministry of Natural Resources and Forestry (MNRF).

Finally, another significant concern for commercial RPAS ventures is the available workforce. As an emerging technology, drones present new challenges and require new skills and training from the Ontario workforce. One significant consideration are training requirements mandated by Transport Canada. Members of RPAS operation crews must receive their Basic or Advanced Pilot Certification depending on the type of operation [3] [33], and businesses must have personnel trained in RPAS maintenance and repairs [33]. Furthermore, RPAS services require personnel with the skills and expertise to manage and process large amounts of data generated by RPAS. New programs are being developed in colleges and universities to meet these new labor market demands and provide the Ontario RPAS Industry with the qualified personnel it needs to grow [60].

5.2.1 Policy Recommendations

The RPAS industry is at a critical juncture in its development, and an effective policy response from the Ontario government is crucial to its future success. The Ontario government should work with industry non-profits and the large businesses that could serve as end-users to bridge the gap between RPAS technology R&D, service providers, and the development of commercial services. It should also be promoting the RPAS industry through industry-led initiatives such as the DAIR hub and the L5 testing facility.

Furthermore, the Ontario government should mobilize its multiple relevant funding programs with OCE, Fed-Dev Ontario, Innovative Solutions Canada, the Strategic Innovation Fund, and other government affiliated programs and agencies to support the creation of new RPAS startups and the growth of existing small businesses in the RPAS sector. This should focus on providing funds for small businesses to purchase new equipment, test and validate systems to ensure safety and reliability, and develop new commercial services. These funds should also encompass a range of match ratios depending on maturity of the business and technology, and the risk of the proposed projects.

Finally, the Ontario Government should expand its support for the use of RPAS in the civil sector by funding the integration of RPAS technologies in existing government services in government ministries and agencies. It should also consider the applications of RPAS technology in large government supported economic development initiatives such as the Ring of Fire mining developments, and efforts to develop the economy of rural or isolated communities such as the Growth Plan for Northern Ontario and Indigenous Economic Development Fund.

5.3 Regulation

The regulation of RPAS operations is critical to ensuring the safety of the public and the Canadian airspace. The regulatory framework that governs the use of RPAS in Canada's national airspace was developed by Transport Canada. These measures are some of the most progressive and well developed in the world, following best practices set by the Joint Authority for Rulemaking on Unmanned Systems (JARUS) [61] and the International Civil Aviation Organization (ICAO) [62]. Their recommendations center around creating a standardized framework for low risk operations, with lower regulatory barriers, and establishing a safety assurance burden proportional to the risk of more advanced operations on a rolling basis [80]. This provides lawmakers the flexibility to extend the standardized framework to cover more advanced operations in the future
-
The Canadian Aviation Regulation (CAR) Part IX, developed in 2019, greatly reduced regulatory uncertainty in the industry by creating 3 distinct classes of operations with specific requirements: basic, advanced, and special operations [33].

- Basic operations cover low risk operations of small drones within visual line of sight, in low altitude, outside of controlled airspace, and away from people. To perform a basic operation, RPAS service providers need to register their aircraft, have personnel receive a basic pilot certification, and comply with basic requirements in terms of safety management systems and procedures.
- Advanced operations allow for operations near or over people, as well as operations within controlled airspace. RPAS operators wishing to perform advanced operations must fly aircraft that meet a safety assurance standard and have personnel meet a higher standard of pilot certification.
- Special operations include operations beyond visual line of sight and the use of aircraft weighing above 25 kg. These operations are authorized on a case by case basis through the Special Flight Operations Certificate (SFOC). RPAS operators wishing to receive an SFOC must provide a detailed operational risk assessment (ORA) and meet specific operational safety requirements corresponding to the risk of the operation.

Growing the Commercial Drone Industry in Ontario

Section 2.3 of this report outlines recent developments in Transport Canada's timeline for the integration of RPAS into the national airspace. This includes the development of more standardized regulations for special operations such as BVLOS flight, as well as a plan to establish a national RTM system. These upcoming regulatory frameworks will have a great impact on the RPAS industry. It is crucial that the Ontario RPAS industry participates in the development of these regulations and is prepared to adapt to this new regime.

While the regulation of Canada's airspace is within the jurisdiction of the federal government, the federal and municipal government have established laws and regulations on the use of RPAS in provincial lands or within municipal boundaries. Bylaws in Toronto, Mississauga, and Hamilton place additional restrictions on drone regulations in those municipalities, which is currently hindering commercial services in these urban areas [82].

Regulations have significant effects on RPAS service providers and the RPAS industry. When laws are not fully established or require a case by case authorization, regulatory uncertainty hinders a business' ability to provide a consistent service and leads to additional financial uncertainty. R&D efforts also benefit from regulatory certainty, as new technologies must be developed with safety assurance and reliability requirements in mind over long time scales. Finally, operational requirements place significant restrictions on current regulations that directly translate to the feasibility of potential commercial services. BVLOS commercial operations would require less equipment and personnel, cover larger distances, and enable completely new commercial use cases such as package delivery and pipeline inspection. In a study conducted by USC on the impact of BVLOS on RPAS commercialization, 70% of Ontario businesses said BVLOS would be critical to their business and estimates the average RPAS industry revenue will increase by 67% with new BVLOS regulations.

5.3.1 Policy Recommendations

Given the impact of regulation on the RPAS industry as a whole, the Government of Ontario and the Ontario RPAS industry should work with all levels of government to ensure regulations maintain a high standard for safety while promoting the development of the commercial RPAS industry. Transport Canada's planned BVLOS regulations and RTM service trials will reduce regulatory uncertainty while providing a pathway towards more complex operations that can improve the value proposition of RPAS services. Ontario RPAS industry stakeholders should be consulted when developing these new frameworks and participate in new opportunities for pilot programs or service trials.

At the federal level, Transport Canada could better support RPAS service providers by assigning more resources to reviewing safety cases and supporting special operations in low risk environments with significant commercial opportunities such as rural infrastructure inspection.

Provincial and municipal policymakers should be effectively briefed on key opportunities, success stories, economic impacts, and growth barriers related to the RPAS industry, and should harmonize their regulations and bylaws with Transport Canada's regulatory framework. They should also develop pilot programs and trials to integrate RPAS services into urban areas to improve the quality of service in municipalities and support the RPAS industry.

Growing the Commercial Drone Industry in Ontario

6. Policy Recommendation Summary

Ontario sits at the cusp of a tremendous opportunity. A new industry of automated aerial operations is emerging, and with most key technologies already mature, but there remains a significant gap in RPAS commercialization. Ontario's drone industry is composed of startups and SMEs who are not fully established, yet there remain industries, such as agriculture, construction, and natural resources, that could greatly benefit from drone technology who are underserved.

Ontario has several strengths that could one day make it a hub of RPAS expertise: world class academic research, a well-structured regulatory framework, and significant support and funding mechanisms for R&D. Nonetheless, the challenge of growing the RPAS industry by developing new commercially viable use cases are complex. The province must adopt a forward-thinking approach to policy to support this nascent industry.

This report recommends that the Government of Ontario:

- Create specific programs within the Ontario Centers of Excellence and other provincial agencies to fund RPAS research and development through public private partnerships.
- Support the participation of Ontario businesses in Transport Canada's Remote Traffic Management service trials and other federal government pilot programs and support the participation of Ontario RPAS businesses in the Downsview Aerospace Innovation and Research Hub and the L5 Autonomous Vehicle Testing Facility.
- Provide longer term funding opportunities for startups small businesses to commercialize new technologies, scale their operations, and develop new commercial services.
- Fund, educate, and support the use of RPAS in government ministries and agencies.
- Include RPAS technology in the plans for the economic development of Northern Ontario, notably the Ring of Fire mining development, and the economic development of indigenous communities.
- Work with the federal government to assign greater resources towards reviewing and supporting Special Flight Operations Certificate applications for lower risk RPAS operations with significant commercial value.
- Brief policymakers at the provincial and municipal government levels on key opportunities, success stories, economic impacts, and growth barriers to growing the RPAS industry.
- Work with municipalities to harmonize bylaws and regulations on the use of RPAS within municipal boundaries and develop pilot programs for the integration of RPAS in urban environments.

Growing the Commercial Drone Industry in Ontario

[1] S. Looper, “Growing the Drone Industry in Ontario”. Ontario Society of Professional Engineers, March 12, 2020. Available: https://ospe.on.ca/wp-content/uploads/2020/03/Growing-the-Drone-Industry-in-Ontario.pdf

[2] N. Budanovic, “The Early Days of Drones – Unmanned Aircraft from World War One and World War Two”. War History Online, May 1, 2017. Available: https://www.warhistoryonline.com/military-vehicle-news/short-history-drones-part-1-x.html

[3] “Knowledge Requirements for Pilots of Remotely Piloted Aircraft Systems 250 g up to and including 25 kg, Operating within Visual Line-of-Sight (VLOS) (TP 15263)”. Transport Canada - Civil Aviation, June 1, 2019. Available: https://tc.canada.ca/en/aviation/publications/knowledge-requirements-pilots-remotely-piloted-aircraft-systems-250-g-including-25-kg-operating-within-visual-line-sight-vlos-tp-15263

[4] K. Singh, A. Frazier, “A meta-analysis and review of unmanned aircraft system (UAS) imagery for terrestrial applications”, International Journal of Remote Sensing. January 3, 2018.

[5] “Machine learning: the power and promise of computers that learn by example”. The Royal Society, April 2017.

[6] A survey of autonomous vision based See and Avoid for Unmanned Aircraft Systems

[7] “Taking Flight”, Technology Quarterly. The Economist, June 10, 2017.

[8] “Drones Reporting for Work, Goldman Sachs Insights. Goldman Sachs, March 2016. Available: https://www.goldmansachs.com/insights/technology-driving-innovation/drones/

[9] “Notice of Proposed Amendment: Remotely Piloted Aircraft Systems Lower-Risk Beyond Visual Line-of Sight”. Transport Canada - Civil Aviation, April 2020.

[10] “RPAS Traffic Management (RTM) Services Trials - Call for Proposals”. Transport Canada - Civil Aviation, May 21, 2020.

[11] D. Mishra, E. Natalizio, “A Survey on Cellular-connected UAVs: Design Challenges, enabling 5G/B5G Innovations, and Experimental Advancements”, Preprint submitted to Elsevier, May 2, 2020. Available: https://arxiv.org/pdf/2005.00781.pdf

[12] A. Ganjoo, M. McNabb, “The Deep Dive into Remote ID for Drones: What It Is, what it Means, and What’s Next”. Drone Life, February 19, 2020. Available: https://dronelife.com/2020/02/19/the-deep-dive-into-remote-id-for-drones-what-it-is-what-it-means-and-whats-next

[13] X. Yu, Y. Zhang, “Sense and avoid technologies with applications to unmanned aircraft systems: Review and prospects” Progress in Aerospace Sciences. January 2015.

[14] “Counter-Unmanned Aerial Systems Technology Guilde”, National Urban Security Technology Laboratory. United States Department of Homeland Security, September 2019.

[15] D. Safadinho, J. Ramos, R. Ribeiro, V. Filipe, J. Barroso, A. Pereira, “UAV Landing Using Computer VisionTechniques for Human Detection”, Architectures and Platforms for Smart and Sustainable Cities, Sensors. January 22, 2020.

[16] “How Artificial Intelligence is Influencing the Drone Industry for Improved Performance”, Financial News Media, July 16, 2020. Available: https://www.prnewswire.com/news-releases/how-artificial -intelligence-is-influencing-the-drone-industry-for-improved-performance-301094576.html

[17] “Ontario Aerospace, Space Defence, UAV and MRO 2019 Capabilities Directory”. Ontario Aerospace Council, 2019.

[18] “Where Information Technology Lives”. InvestOntario, 2020. Available: https://www.investinontario.com/brochures/publication/where-information-technology-lives

[19] “Industrial Automation and Robotics”, InvestOntario, 2020. Available: https://www.investinontario.com/industrial-automation-and-robotics#robotics-intro

[20] Unmanned Systems Canada Member Directory. Available: https://www.unmannedsystems.ca/member/ [Accessed August 4 2020]

[21] https://my-ibisworld-com.myaccess.library.utoronto.ca/us/en/industry-specialized/od4424/industry-at-a-glance

[22] AUVSI https://02f09e7.netsolhost.com/AUVSIDocs/Global%20Trends%20for%20UAS.pdf

[23] “Emerging Trends in Real Estate: Canada and the United States 2020”. PricewaterhouseCoopers and Urban Land Institute, 2020. Available: https://www.pwc.com/ca/en/industries/real-estate /emerging-trends-in-real-estate-2020.html

[24] “Real estate agents, brokers, appraisers and other real estate activities, 2017”, The Daily, Statistics Canada, February 22, 2020. Available: statcan.gc.ca/n1/daily-quotidien/190222/dq190222d-eng.html

[25] P. Gabrielli, “Why you Should Invest in Drones for Real Estate Marketing”. Meero, April 18, 2019. Available: meero.com/en/news/real_estate/459/Why-You-Should-Invest-In-Drones-For-Real-Estate-Marketing

[26] “2020 Facts of the Property and Casualty Insurance Industry in Canada”. Insurance Bureau of Canada, 2020. Available: www.ibc.ca/on/resources/industry-resources/insurance-fact-book

[27] “Clarity from Above: PwC global report on the commercial applications of drone technology”, PricewaterhouseCoopers, May 2016.

[28] Statistics Canada: Construction Industry. Available: https://www150.statcan.gc.ca/n1/en/subjects/Construction [accessed August 8 2020]

[29] A. Reeves, J. Ryan “Pipelines in Canada”. The Canadian Encyclopedia, January 30, 2020. Available: https://www.thecanadianencyclopedia.ca/en/article/pipeline

[30] “Ontario’s Pipeline Regulatory Regime”. Natural Resources Canada. Available: https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/clean-fossil-fuels/pipelines/pipeline-safety-regimes-canada/ontarios-pipeline-regulatory-regime/16443

[31] “Minerals and the Economy”, Natural Resources Canada, December 3, 2019. Available: https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-and-economy/20529

[32] “Mining”, InvestOntario. Available: https://www.investinontario.com/mining#secure [Accessed August 10 2020]

[33] G. Balamurugan, V. Jayaraman, D. Naidu, “Survey on UAV navigation in GPS denied environ-ments”, International conference on Signal Processing, Communication, Power and Embedded System (SCOPES). October 2016.

[34] W. Ahmed, “Measuring Ontario’s Urban-Rural Divide”. Ontario 360, November 13, 2019.

[35] D. Jenkins, B. Vasigh, C. Oster, T. Larsen, “Forecast of the Commercial UAS Package Delivery Market”. Embry Riddle Aeronautical University, May 2017.

[36] “Find your category of drone operation”. Transport Canada. Available: https://tc.canada.ca/en/aviation/drone-safety/find-your-category-drone-operation

[37] Statistics Canada, Agriculture in Canada. Available: https://www150.statcan.gc.ca/n1/pub/95-629-x/1/4182379-eng.html [Accessed August 8 2020]

[38] V. Puri, A. Nayyar, L. Raja, “Agriculture drones: A modern breakthrough in precision agriculture”, Journal of Statistics and Management Systems, Issue 4: Machine Learning and Software Systems, Volume 20. November 16, 2017.

[39] “An Overview of Aboriginal Health in Canada”. National Collaborating Center for Aboriginal Health, University of Northern British Columbia, 2013. Available: https://www.ccnsa-nccah.ca/docs/context/FS-OverviewAbororiginalHealth-EN.pdf

[40] “Drone Delivery Canada Signs $2.5 Million Commercial Agreement with Moose Cree First Nation to Deploy DDC’s Drone Delivery Platform”. Drone Delivery Canada Press Release, December 5, 2018.

[41] “Ontario’s Energy Sector”, Ontario Energy Board. Available: [Accessed August 10 2020] https://www.oeb.ca/about-us/mission-and-mandate/ontarios-energy-sector

[42] “Provincial and Territorial Energy Profiles”. Canada Energy Regulator. Available: https://www.cer-rec.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/on-eng.html

[43] J. Knope, “Here’s what Toronto’s $2B-a-year film industry could look like once it reopens”. CBC News, May 23, 2020. Available: https://www.cbc.ca/news/canada/toronto/unions-toronto-officials-explore -ways-bring-back-film-industry-1.5579297

[44] S. Zacharek, “How Drones Are Revolutionizing the Way Film and Television Is Made”. Time, May 31, 2018. Available: https://time.com/5295594/drones-hollywood-artists/

[45] University of Toronto Institute for Aerospace Studies Centre For Aerial Robotics Research and Education. Available: https://carre.utoronto.ca/ [Accessed August 14 2020]

[46] Carleton University Uninhabited Aircraft Systems Training, Innovation and Leadership Initiative. Available: https://carleton.ca/utili/ [Accessed August 14 2020]

[47] Vector Institute, Available: https://vectorinstitute.ai/ [Accessed August 14 2020]

[48] Natural Sciences and Engineering Research Council of Canada, Collaborative Research and Training Experience Program. Available: https://www.nserc-crsng.gc.ca/professors-professeurs/ grants-subs/create-foncer_eng.asp [Accessed August 13 2020]

[49] "Ottawa L5 Testing Facility", InvestOttawa. Available: https://www.investottawa.ca/ottawal5/ [Accessed August 13 2020]

[50] C. Egusa, V. Stunt, "Canada is North America's up-and-coming startup center", TechCrunch, April 20, 2017. Available: techcrunch.com/2017/04/20/canada-is-north-americas-up-and-coming-startup-center/

[51] FedDev Ontario Regional Innovation Ecosystem Program. Available: feddevontario.gc.ca/eic/site/723.nsf/eng/02474.html?OpenDocument [Accessed July 17 2020]

[52] Ontario Centers of Excellence SmartStart Seed Fund. Available: https://www.oce-ontario.org/programs/archived-programs/smartstart-seed-fund [Accessed July 17 2020]

[53] I. Kirkwood, "Report: Canadian VC Investments Set REcord in 2019 as Tech Sector Dominates". Betakit, March 11, 2020. Available: betakit.com/report-canadian-vc-investments-set-record-in-2019 -as-tech-sector-dominates/

[54] The Conference Board of Canada, Venture Capital Provincial and Territorial Ranking. Available: https://www.conferenceboard.ca/hcp/provincial/innovation/venture-capital.aspx?AspxAutoDetectCookieSupport=1 [Accessed July 23 2020]

[55] Natural Sciences and Engineering Research Council of Canada, Alliance Grants. Available: nserc-crsng.gc.ca/Innovate-Innover/alliance-alliance/index_eng.asp [Available August 4 2020]

[56] Mitacs Accelerate Program. Available: https://www.mitacs.ca/en/programs/accelerate [Accessed August 4 2020]

[57] Ontario Centers of Excellence Voucher for Innovation and Productivity. Available: https://www.oce-ontario.org/programs/voucher-for-innovation-and-productivity-(vip [Accessed August 4 2020]

[58] Downsview Aerospace Innovation and Research Hub. Available: www.dairhub.com/#hub [Accessed August 6 2020]

[59] Unmanned Systems Canada, About Us. Available: www.unmannedsystems.ca/about-us/ [Accessed August 7 2020]

[60] Mohawk College RPAS (Drone) Certification Training and Flight Review Program. Available: .mohawk-college.ca/ce/programs/technology-and-skills/rpas-drone-certification-training-and-flight-review

[61] "JARUS Guidelines of Specific Operational Risk Assessment". Joint Authorities for Rulemaking on Unmanned Systems, March 6, 2019.

[62] International Civil Aviation Organization Model UAS Regulations. Available: https://www.icao.int/safety/UA/UAID/Pages/Model-UAS-Regulations.aspx

[63] K. McCulloch, “Canada: Municipal Bylaws Impacting Drone Operations – Are They Legal?”, Mondaq, September 19, 2019. Available: https://www.mondaq.com/canada/aviation/836266/municipal-bylaws-impacting-drone-operations-are-they-legal

ONTARIO
SOCIETY OF
PROFESSIONAL
ENGINEERS

Follow Us @O_S_P_E