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AVIN INSIGHTS

Smart Mobility for Off-Road Use:

Developments and Opportunities in the Agriculture Industry

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INTRODUCTION

The development and deployment of smart mobility solutions are attracting companies', governments', and consumers' interest worldwide, as they promise radical improvements to on-road safety, travel efficiency, and passenger convenience. While it is not fully clear when we will have smart mobility solutions as mainstream on our roads, these technologies have been revolutionizing several industries with their "off-road" use. Autonomous and connected vehicles have already arrived in places other than our roads and have revamped the operations of many industries that are built on mobility using vehicles designed specifically for off-road use. The advantage of a controlled environment has helped these industries march ahead of on-road mobility.

Agriculture is one of these off-road industries that have been leveraging the advances of smart mobility technologies and solutions for many years. The cost and availability of human labour have been major driving forces for leveraging these technologies as effective and complementing solutions. Tractors can drive with no farmer in the cab and specialized autonomous machinery - both ground and aerial - are able to seed, weed, spray, and harvest crops.

The benefits of using autonomous and connected vehicles in agricultural fields and farms have proved to be equally – if not more – rewarding for owners, operators, and consumers. The use of smart mobility in the agriculture industry has been rewarding for the technology itself as well. Fields and farms are serving as testing and proving grounds for these technologies as they are advancing to make their mark in the transportation realm.

In this report, we touch upon the various forces driving the use of smart mobility in the agriculture industry. We also focus on delineating the various forms and types of smart mobility

technologies that are part of the technological transformation we see increasingly in agricultural fields and farms. We complement the discussion by highlighting some of the major developments and opportunities experienced worldwide in the context of smart mobility for agricultural use. We anticipate that the discussed developments and opportunities will massively expand over the coming years as the technology evolves and more farmers adopt these technologies as worthwhile solutions for the challenges they face and valuable means for increasing economic and environmental stewardship benefits.
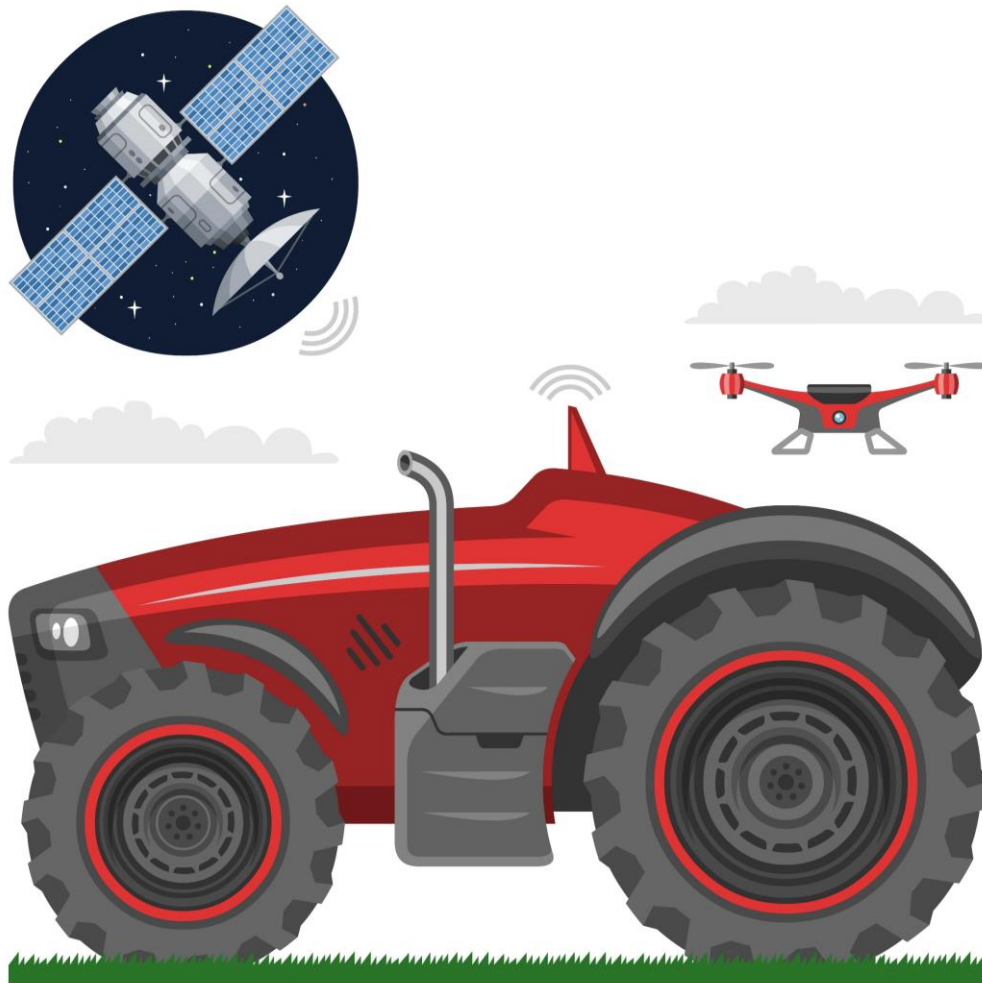
SMART MOBILITY IN AGRICULTURE

The agriculture industry has experienced significant technological advances over the past 50 years. Advances in agriculture equipment have resulted in expansion of both operational efficiency and cultivated lands.

Nowadays, the industry is facing some challenges that are calling for another technological revolution.

In this section:

According to the Food and Agriculture Organization of the United Nations (FAO)[1], the world's population is expected to grow to almost 10 billion by 2050. Building on this expectation, the European Agricultural Machinery Association (CEMA) has predicted that agricultural production must increase by 70 percent by 2050 to feed this growing population[2]. Meeting these huge demands is a critical challenge that the agriculture industry needs to tackle. Increasingly, the sector faces labour shortages, rising costs for agriculture work and production. Many landowners are facing the challenge of increasing production, while struggling to find labour to support operations[3]. According to the Canadian Agricultural Human Resource Council (CAHRC)[4], in 2019, farmers across Canada's agriculture sector reported $2.9 billion in lost sales due to labour shortages – an increase from $1.5 billion in 2014.

In the face of the growing food demands and labour shortages, the agriculture industry has to turn to technology to boost the production efficiency and scale. At the heart of this technological support, autonomous and connected mobility machines form potentially effective solutions for the faced challenges. From seeding and planting to weeding and harvesting, every stage in agriculture and farming can benefit significantly from the technological advances in autonomous and connected ground and aerial vehicles, as detailed below.

70% *increase of agricultural production is needed by 2050 to feed the growing population.[2]*

[1] **The Food and Agriculture Organization (FAO). (2017). The future of food and agriculture: Trends and challenges. Retrieved from** http://www.fao.org/3/a-i6583e.pdf

[2] **The European Agricultural Machinery Association (CEMA). (2019). Promoting Sustainable Agricultural Mechanization in Africa. Retrieved from** https://www.cema-agri.org/images/publications/position-papers/CEMA_Promoting_SAMA_Position_2019.pdf

[3] **RealAgriculture. (2018). Automation is changing modern farming. Retrieved from** https://www.realagriculture.com/2018/08/automation-is-changing-modern-farming/

[4] **The Canadian Agricultural Human Resource Council (CAHRC). (2019). Canada's Ag Sector Loses 2.9 Billion Due to Labour Shortages. Retrieved from** https://cahrc-ccrha.ca/news-events/news-releases/canada%E2%80%99s-ag-sector-loses-29-billion-due-labour-shortages

Autonomous Vehicles and Robots

Complementing human labour with autonomy is a growing trend across multiple industries[5,6], and agriculture is no exception. Within the next decade, the agriculture industry will radically revolutionize by the expanded use of autonomous vehicles and robotics to complement and solve shortage in human labour, increase productivity, and reduce environmental impacts. Partially and fully autonomous tractors and agricultural machinery are leveraging the evolution of artificial intelligence to bring smart mobility to the agricultural sector. Advanced positioning technologies (e.g., GPS), computer vision techniques, and automation systems have led to successful testing and deployment of a variety of autonomous agricultural equipment to work simultaneously with minimal human intervention, freeing up time and resources that human labour can better utilize. Autonomous machines have also proved to accomplish field work more efficiently and precisely than human-operated ones, generating fuel savings and higher yields[7]. Unlike humans, autonomous machines usually have the ability to work regardless of time, light, and weather conditions that can impact a human's ability to work for extended lengths of time or time of day. This leads to boosting land production to greater levels.

It is worth noting that the agriculture industry is well suited to embrace autonomous vehicles and robots, in a pace much faster than on-road environments. This is due to the lower complexity of the agricultural environments that usually encompass defined tasks and bounded areas that limit safety concerns, as opposed to navigating busy streets and intersections[8]. Building on this fact, Invest Ottawa and other founding partners, with

[5] **Autonomous Vehicle Innovation Network (AVIN). (2020). Leading the Future of Goods Movement: Drivers of Change, Transformations, and Opportunities. Retrieved from** tinyurl.com/ydes642v

[6] **Autonomous Vehicle Innovation Network (AVIN). (2019). Autonomous Vehicles Reshaping the Future: Cross-Sector Opportunities and Considerations. Retrieved from** tinyurl.com/1ljhx9ty

[7] **McKinsey & Company. (2020). Agriculture's connected future: How technology can yield new growth. Retrieved from** https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth

[8] **BLG. (2020). The future of farming — Autonomous agriculture. Retrieved from** https://www.blg.com/en/insights/2020/03/the-sensor-the-future-of-farming-autonomous-agriculture

the support of the Government of Ontario through AVIN, have recently announced the launch of Area X.O, which includes the Ottawa Smart Farm[9]. One of the main targets of this smart farmland is to facilitate the development, testing, and commercialization of new agricultural technology solutions, including autonomous vehicles.

Realizing the opportunities and benefits brought by autonomous vehicles and robots, many agriculture machinery companies are working on the autonomous machinery front[10]. According to a market research report by MarketsandMarkets[11], the agricultural robots market is projected to grow from USD 4.6 billion in 2020 to USD 20.3 billion by 2025, driven by the potential of autonomous machinery to lower costs while increasing productivity.

We have already started to see heavy-duty agricultural robots - or AgBots – fulfilling duties at farms and agricultural fields. We also see swarm robots - or SwarmBots - which are small, lightweight, high-tech robotic machines that operate in swarms to collaboratively perform agricultural tasks.

These robots are equipped with autonomous mobility technologies, making them prominent examples of autonomous vehicles (AVs). These types of AVs take different forms and are able to handle a variety of agricultural tasks, as per below.

The agricultural robots market is projected to grow from USD 4.6 billion in 2020 to USD 20.3 billion by 2025.[11]

[9] **Invest Ottawa. (2020). First Smart Farm of Its Kind in Canada Launches in Ottawa at Area X.O. Retrieved from** https://www.investottawa.ca/blog/first-smart-farm-of-its-kind-in-canada-launches-in-ottawa-at-area-x-o/

[10] **Kondinin Group. (2017). Autonomous Tractors: The Rise of the Robots. Retrieved from**

https://www.farmingahead.com.au/digital_assets/eee4d8df-ebd0-4e93-a47239a985d78f47/Research-Report-Autonomous-tractors-88.pdf

[11] **MarketsandMarkets. (2020). Agricultural Robots Market. Retrieved from** https://www.marketsandmarkets.com/Market-Reports/agricultural-robot-market-173601759.html

Driverless Tractors

The most prominent example of autonomous agricultural vehicles is the driverless tractor. Goldman Sachs predicts that agriculture technologies could become a $240 billion market opportunity for agriculture suppliers, with driverless tractors a $45 billion market on its own[12]. The various driverless tractors introduced to the market are split into full autonomous technology and supervised autonomy that can be controlled remotely. All major tractor manufacturers have plans and concepts in the works towards full autonomy.

Since its acquisition of NavCom Technology in 1999, the agricultural, construction, and forestry equipment giant John Deere has been working on autonomy for its tractors. One of the first results of those efforts was the company's AutoTrac assisted steering system. Since its introduction, every new John Deere tractor has included some form of autonomy via the company's AutoTrac system. The development of a driverless tractor was a natural evolution of the company's efforts to advance its autonomous systems that has continued over the years. The latest addition to John Deere's fleet of autonomous agricultural machinery was the driverless tractor

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[12] **Daniels, F. (2016). Future of farming: Driverless tractors, ag robots. Retrieved from**

https://www.cnbc.com/2016/09/16/future-of-farming-driverless-tractors-ag-robots.html

concept revealed at the end of 2019 at AgriScot, one of the premier events in UK agriculture[13]. This driverless tractor is also electric, using 500 kilowatts of power, and can be equipped with either wheels or tracks. The tractor's autonomous driving system is capable of delivering sub-inch level of accuracy, helping farmers avoid running over healthy crops or leaving fertile soil untouched.

It is not only John Deere that is driving the evolution of driverless tractors. In 2016, Case IH, a global agricultural equipment brand of CNH Industrial, revealed its concept driverless tractor at the Farm Progress Show in Iowa[14]. The vehicle is developed in collaboration with Autonomous Solutions Inc. and built on the chassis of a conventional tractor. The concept tractor is equipped with GPS and sensor technologies, and it enables farmers to monitor and control its function via a tablet or a computer. The vehicle is also capable of sending out alerts, so the farmer can know when it is running low on fuel, for

example. Since revealing the concept autonomous tractor, the company has continued to evolve the technology and validate it through field pilots.

In the 2020 Farm Progress show, Raven Industries Inc. showcased its DOT Power Platform that is capable of completing farm tasks autonomously. The platform was initially developed by the Canadian DOT Technology Corp., before its acquisition by Raven. The built-in-Canada autonomous farming platform is currently being tested at a number of farm locations in Ontario, where it appeared first in mid-2020 at a farm in Chatham-Kent[15]. The platform is also being used in Alberta by the Olds College. The agricultural college announced that it has deployed the DOT platform as a teaching and research tool on the College's Smart Farm[16]. Another solution from Raven Industries is AutoCart, which allows an operator to control a driverless tractor and grain cart directly from the cab of a harvester[17]. In late 2020, Raven Industries announced the opening of a new

[13] **John Deere. (2019). New tractors make show debut at AgriScot 2019. Retrieved from**
https://www.deere.co.uk/en/our-company/news-and-media/press-releases/2019/November/AgriScot-tractor-debut-2019.html
[14] **CNH Industrial. (2016). CNH Industrial brands reveal concept autonomous tractor development: driverless technology to boost precision and productivity. Retrieved from**
https://tinyurl.com/5ggsuqhq
[15] **CBC News. (2020). Robo farm: AI machine 'DOT' comes to an Ontario farm for the first time. Retrieved from**

https://www.cbc.ca/news/canada/windsor/ai-machine-the-dot-comes-to-ontario-farm-first-time-1.5581327
[16] **Olds College. (2020). Olds College to Use Autonomous Equipment in the Field. Retrieved from**
https://www.oldscollege.ca/about/news/2020/olds-college-to-use-autonomous-equipment-in-the-field/index.html
[17] **Raven. Driverless AG Technology. Retrieved from**
https://ravenprecision.com/raven-autonomy/driverless-ag-technology

facility for precision and autonomous agriculture innovation, training, and service near Regina, SK[18].

Other companies are focusing on developing technologies to transform conventional tractors into autonomous ones. For example, the Minnesota-based Autonomous Tractor Corp. developed the AutoDrive package to turn used tractors into autonomous machines. The system taps into the tractor's electronics and, using sensors, radio signals, and artificial intelligence, takes over the control[19].

Seeding

Seeding is one of the agricultural tasks that is typically done manually by human labour. With the introduction of human-operated seeding machines, increases in both the rate and efficiency in which crops could be planted were gained. However, these machines lack full precision in distributing seeds, resulting in waste of both seeds and fertile soil.

Autonomous seeding machines have been

introduced to solve the inaccuracy of the human-operated ones. Using precise geomapping, they can accurately cover the designated land and drop seeds with high precision and at specified seeding densities. They can also be programmed to optimize the spacing between plants to allow for optimal growth and best utilization of the farmland. Moreover, they can be equipped with sensors that autonomously measure soil quality and nutrient levels, which are beneficial parameters for the seeding process to correspondingly control the seed depth and density[20]. These seeding machines can either be deployed as an attachment to a driverless tractor or used standalone as seed sowing robots/vehicles.

[18] **Business Wire, Inc. (2020). Raven Industries Expands Strategic Growth Initiative in Canada. Retrieved from** https://www.businesswire.com/news/home/20201110005060/en/Raven-Industries-Expands-Strategic-Growth-Initiative-in-Canada

[19] **Wehrspann, J. (2016). Step-by-step conversion to make a tractor driverless. Retrieved from**

https://www.farmprogress.com/row-crop-tractors/step-step-conversion-make-tractor-driverless

[20] **Brown, M. (2018). Smart Farming—Automated and Connected Agriculture. Retrieved from** https://www.engineering.com/story/smart-farming-automated-and-connected-agriculture

An example of a market-ready seeding robot is the AGCO/Fendt Xaver. In this three-wheeled concept, the last wheel not only drives the robot, but also, when it passes over, it compacts the soil gently to the side and above the seed row. The latest generation of this robot is also equipped with a lane guidance system that controls the robot with centimetre-accuracy. This small robot is deployed as a part of a swarm, with the group of robots acting autonomously round-the-clock. Fendt claims that, with the electric drive and negligible pressure impact on the field from the low weight, these seed sowing robots have no air pollutants or noise emissions, nor can they leak oil[21].

Weeding, Spraying, and Crop Maintenance

In addition to tractors and seeders, autonomous weeders are also on the rise. Weeding is not usually an easy task, as it is sometimes challenging to identify weeds in the crop. Therefore, farmers usually spray the entire field with chemicals to kill weeds and maintain crops. This "one size fits all" approach can result in wasteful overuse of sprays, as well as environmental harm. Also, handling sprays by humans can directly expose workers to these chemicals and their dangerous effects.

Bringing autonomy to weeding, spraying, and crop maintenance brings significant efficiency to these tasks, tackles labour shortage, and helps avoid the above-mentioned concerns. Using cameras and computer vision, autonomous robots and vehicles can accurately identify weeds, facilitating targeted maintenance and spraying, instead of broadcast-spraying. According to real use cases, this reduces herbicide use by more than 95 percent[22]. It also greatly limits the spread of and exposure to chemicals for humans.

Building on these enormous benefits, many companies have been working on developing autonomous, mobile weeders and sprayers that can be connected to autonomous tractors or work in isolation. An example is the See & Spray machine developed by Blue River Technology, a company acquired by John Deere in 2017. Using computer vision, the machine detects weeds and precisely sprays herbicides only

[21] **Fendt. (2020). Latest generation of seed sowing robots: The Fendt Xaver comes of age. Retrieved from** https://www.fendt.com/int/2-fendt-xaver

[22] **Johnson, N. (2020). Self-driving tractors, robot apple pickers: Witness the high-tech future of farming. Retrieved from** https://grist.org/food/self-driving-tractors-robot-apple-pickers-witness-the-high-tech-future-of-farming/

where needed. According to the company, this mechanism eliminates about 90 percent of the herbicide volumes sprayed today, while opening the potential to use other herbicides that are not appropriate for broadcast-spraying[23].

More environment-friendly autonomous weeders are the ones developed by the French company, Naïo Technologies. After identifying weeds, these electric robot vehicles are capable of removing weeds from row crops. Naïo has developed three different weed-picking robots: the lightweight Oz, designed for small farms and greenhouses; Ted, designed for vineyards; and Dino, designed to tackle weeds on large-scale farms[24]. A similar weeding technology has been developed at University of California Davis with support from the US Department of Agriculture. Instead of being a standalone robot, the automated cultivator can be towed behind a tractor to identify weeds in a row of crop plants and cut them out of the soil[25]. This automated cultivator is not the only academic-based design and production in this space. In Canada, a University of British Columbia student design team is developing a fully autonomous agricultural robot,

[23] **Blue River Technology. Our See & Spray machines. Retrieved from** http://smartmachines.bluerivertechnology.com/

[24] **Naïo Technologies. Automated Robots and Farming Tools. Retrieved from** https://www.naio-technologies.com/en/agricultural-equipment/

[25] **UC Davis. (2015). UC Davis developing faster, more accurate robotic cultivator. Retrieved from** https://www.ucdavis.edu/news/uc-davis-developing-faster-more-accurate-robotic-cultivator/

named "UBC AgroBot"[26]. This robot can analyze its environment and perform targeted weeding, fertilizing, and soil analysis through the use of advanced robotics, image recognition, and machine learning. The project has received financial support from various organizations, including Farm Credit Canada (FCC).

Another environment-friendly weeder is the robot developed by Bosch's Deepfield Robotics that also uses imaging and machine learning to identify weeds. But, instead of pulling/cutting weeds out or hosing them with herbicides, the mobile robot uses a ramrod to smash weeds into the ground[27].

Harvesting

Harvesting crops seems very challenging to be handled by machines as they might cause damage while picking delicate crops, such as tender fruits. However, some companies have accepted the challenge and developed autonomous harvesting machines that can handle plants and

produce very gently and efficiently. An example is Abundant Robotics that has developed an apple picking robot[28]. The robot navigates the rows between apple trees using LiDAR and uses computer vision to locate and scan apples on the trees. If the fruit is identified to be ripe, the system triggers the robotic arm to pick it. The arm uses a vacuum tube to suck the fruit off the plant. The robot can do this 24 hours a day, boosting productivity and efficiency beyond human pickers while significantly lowering the cost. Panasonic, the global electronic technologies and solutions provider, has contributed to this field and developed a tomato harvesting robot. The mobile robot is equipped with a camera and uses image recognition to find the tomatoes and determine whether they should be harvested or not. If a tomato is ripe, it passes it through a ring, then pulls on it, as if it is taken by hand[29]. These are only a few examples of up-and-coming autonomous robots and vehicles that are likely to eventually take over the whole harvesting process, solving the challenges of human labour.

[26] **UBC AgroBot. UBC AgroBot Design Team. Retrieved from** https://ubcagrobot.com/

[27] **Farming Revolution GmbH. AI-powered weeding robots for your organic farm. Retrieved from** https://www.farming-revolution.com/

[28] **Abundant Robotics, Inc. Accessed through** https://www.abundantrobotics.com/

[29] **Panasonic Co. (2018). Introducing AI-equipped Tomato Harvesting Robots to Farms May Help to Create Jobs. Retrieved from** https://news.panasonic.com/global/stories/2018/57801.html

The above-mentioned examples are standalone mobile robots built from scratch with autonomy in mind. Other solutions have been introduced to the market to transform manned harvesters to autonomous ones by equipping them with the needed technologies. An example is the Cognitive Agro Pilot that does not only allow a combine to steer itself, but also to understand and react to its surroundings[30]. The technology has been proven in industrial use across 35 regions of Russia during the 2020 harvest. Over 350 New Holland, John Deere, and Claas combine harvesters equipped with the Cognitive Agro Pilot system farmed over 160,000 hectares of field and harvested more than 720,000 tons of crops. In late 2020, the Cognitive Pilot was honored for Overall Harvesting Innovation of the Year at AgTech Breakthrough Awards for being capable of increasing the efficiency of combine harvesters by up to 25 percent, cutting fuel costs, and preventing accidents on the field.

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[30] **Cognitive Robotics. Cognitive Agro Pilot - Your Crop-Harvesting Assistant. Retrieved from**   https://en.cognitivepilot.com/products/cognitive-agro-pilot/

Agricultural Drones

Other forms of smart mobility that have already begun transforming agriculture are drones. Equipped with cameras, sensors, and artificial intelligence technologies, drones can provide farmers with a bird's eye view of their fields. They can also be equipped with advanced technologies and hardware that enable more diverse agricultural tasks. Reducing the dependency on the limitedly available human labour and leaning on these efficient technologies help reduce costs and improve production and yields, generating between $85 billion and $115 billion in value by 2030, according to Mckinsey & Company[7].

Field **imaging** and **monitoring** via autonomous drones have been popular

given the relative accuracy and ease of use. These technologies can be used to collect detailed data on fields and crops, providing farmers with broader views and inputs for monitoring crop health and assessing soil quality. Another common use of drones in agriculture is to monitor and analyze environmental pressures like water stress, insect pressure, or disease[31]. Advanced drones can also be used to create 3D images of the field to plan for future use, handling, and upgrades.

Yet, it is not only imaging and field monitoring that bring drones to the agricultural fields. Autonomous drones have also been seen handling **irrigation** on a wide scale. It is not only about spraying
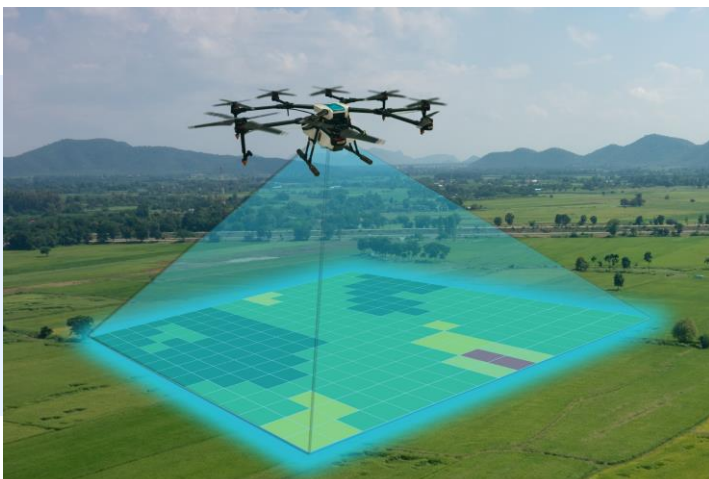
31 **The Canadian Association of Agri-Retailers (CAAR). (2016). The Impact of Autonomous Technology. Retrieved from**

https://caar.org/the-communicator/december-2016/438-the-impact-of-autonomous-technology

water over the field, but also, they can be equipped with thermal sensors to assess the soil moisture and automate proper and targeted irrigation accordingly. Similar to ground autonomous vehicles and robots, drones have also been used for precise **seeding**, **weeding**, and **spraying**. Thanks to precise sensing and navigation technologies, drones can distribute seeds and chemicals precisely and evenly, avoiding wastes and reducing harm to the environment. Autonomous drones also bring the ease and flexibility of handling these tasks in remote locations, lowering equipment and labour costs. Drones have also been considered a promising solution for crop **harvesting** with its zero chance of soil compaction.

Such uses of autonomous drones in agriculture are not conceptual or visionary. Drones have been available in the agricultural market for many years with many companies providing various technologies to handle different agricultural tasks. For example, XAG, a Chinese manufacturer of agricultural drones, has launched a drone for rice seeding, to mitigate the shortage of labour in agriculture[32]. The JetSeed, an intelligent granule spreading system mounted on the bottom of the drone, generates high-speed airflow to project seeds accurately into the targeted topsoil, while maintaining optimum spacing and uniform plant density. In April 2020, the technology was demonstrated and compared to manual

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[32] **XAG Co. (2020). Automated Farming: XAG Introduces Rice Seeding Drone to Mitigate Labour Shortage. Retrieved from** https://www.xa.com/en/news/official/xag/83

seed broadcasting in China's Happy Farms. Two workers were invited to spread 5 kg of rice seeds, which took them 25 minutes to cover 1,200 square metres of land. The XAG's drone finished the same amount of work in only two minutes.

Another example of agricultural drone manufacturers is DJI that has developed Agras MG-1, a drone designed specifically for crop spraying[33]. The drone can carry up to 10 kg liquid payloads, including pesticides and fertilizers, and handle spraying 40 to 60 times faster than manual spraying. The spraying system automatically adjusts its spray volume and strength according to the flying speed to make sure that the pesticide or fertilizer is precisely regulated to avoid pollution and waste. Another crop spraying drone is one built by Volocopter and John Deere, known as VoloDrone[34]. This large drone comes with a potential payload of 200 kg, making it able to cover a large area. The VoloDrone has a fully electric drive, with one battery charge allowing a flight time of up to 30 minutes. The drone can be operated both remotely and autonomously, on a pre-programmed route. John Deere offers

another drone sprayer with a smaller payload. This drone is autonomous and equipped with a weed scanner and crop sprayer, allowing weeds to be scanned from the air and treated accordingly. The 10.6 litre tank is filled fully autonomously at a field boundary station, where the drone's battery can also be autonomously charged[35]. Forward Robotics, a start-up based in Kitchener, ON, has also joined the revolution and developed the U7AG drone sprayer[36]. This drone enables fixed-wing spraying at 120 km/h with a 7 m boom, while simultaneously being capable of fully autonomous, ultra-fast refilling.

Although it sounds quite challenging, some companies have succeeded in developing drones for fruit and vegetable harvesting. An example is the autonomous drone developed by Tevel Aerobotics Technologies, that is capable of picking fruits, including apples, oranges, and avocados[37]. Using computer vision, the drone scans the trees and picks only the fruit that is ripe using an attached three-foot-long claw. The drone can also handle other tasks such as thinning and pruning trees.

[33] **DJI. AGRASMG-1. Retrieved from**
https://www.dji.com/mg-1
[34] **Volocopter. Heavy-lift utility drone for agriculture. Retrieved from**
https://press.volocopter.com/index.php/john-deere-and-volocopter-cooperate-on-cargo-drone-technology
[35] **Deere & Company. Future of Farming. Retrieved from**
https://www.deere.co.uk/en/agriculture/future-of-farming/
[36] **Forward Robotics Inc. U7AG Aerial Application Drone. Retrieved from**
http://www.forwardrobotics.com/u7ag
[37] **Tevel Aerobotics Technologies. The best fruit pickers in the world, by FAR™. Retrieved from**
https://www.tevel-tech.com/

Connected Vehicles and Robots

Smart mobility goes beyond autonomy to include connectivity between vehicles, their surroundings, and remote entities as well. Connected vehicles bring major benefits for their users and enhance the efficiency of the other technologies and systems available in the vehicle. For instance, connectivity in vehicles helps enhance autonomy through boosting the accuracy of the on-board autonomous systems. Connected vehicles and robots can collect data and information about their surroundings, that can complement sensing-based detection systems. In the context of the agriculture industry, Mckinsey and Company predicts that increasing the autonomy of machinery through better connectivity could create $50 billion to $60 billion of additional value by 2030[7].

Furthermore, connecting agricultural vehicles and robots to a computing cloud in real time can help offload some of the heavy processing tasks supposed to be done by the machine itself to the remote cloud. This can help simplify the design requirements and resources of the machines, which leads to lowering the cost of these machines and simplifying their use. With the advances in telecommunication technologies and the improved speeds brought by 5G, this can be a trending approach soon[38].

Connectivity in agricultural vehicles is also a major enabler for real-time field and crop monitoring. Connected vehicles and machinery can collect vital data directly from the fields and facilitate sharing it with farmers in real time, so they can take

$50-$60 billion

of additional value can be created in the agriculture industry by 2030 by increasing autonomy of machinery through better connectivity.[7]

[38] **GSMA. (2020). Smart Farming: Weed Elimination with 5G Autonomous Robots. Retrieved from**

https://www.gsma.com/iot/wp-content/uploads/2020/02/Smart-Farming-weed-elimination-final-for-web-170220.pdf

prompt actions when required. Such real-time oversight is a booster for operational efficiency and a valuable means for avoiding serious risks, since early signs of potential harm can be reported for actions right as they happen.

To reap all the benefits brought by connected vehicles and robots, many of the agricultural machinery manufacturers have equipped most of their offered machines with a means of connectivity. John Deere, for instance, equip their autonomous tractors with a connected vehicle technology that helps tractors talk to each other to exchange not only safety information, but also data on which areas of the field they have finished working on. This data along with other data on soil and crop health and status can also be reported to and stored in John Deere's cloud with access by farmers to make informed decisions[39].

Tractors in Case IH's Magnum AFS Connect series also come with wireless connectivity and data transfer features. These models recognize the importance of data to today's farmers and enable reporting of operational data, such as machine position and

performance, needed supplies, and areas worked, all securely and in real time. This data can be accessed through the Case IH AFS Connect portal available through the company website, allowing farmers to remotely manage their fields and machines from their offices or homes via any Internet-connected device[40].

The AGCO/Fendt Xaver seeding robot highlighted earlier is another example of the agricultural connected machines. The robot operates with connectivity to the cloud to receive commands and return its status reports. The system can be remotely managed via the Xaver app or the FendtONE web portal[20].

Connectivity is not only for ground vehicles, but it has been brought to aerial vehicles as well. Many agricultural drones have been equipped with a communication technology for the same reasons mentioned above. The Tevel Aerobotics Technologies' fruit-picking drone is an example. As the drone works, it sends updates to the farmers on how many pieces of fruit have been picked and how much time it will take to finish the harvesting job.

[39] Bigelow, P. (2019). Autonomous technology has grown deep roots in the farming sector. Retrieved from https://www.autonews.com/shift/autonomous-technology-has-grown-deep-roots-farming-sector

[40] Case IH. (2020). Magnum™ AFS Connect™: the next level in data monitoring and management – and new cab comfort standards. Retrieved from https://tinyurl.com/mew9611b

These are only a few examples of the many agricultural equipment companies that utilize connected vehicles for real-time field and machinery monitoring and control. Some companies have also utilized connectivity in vehicles in other ways. Fendt, for example, introduced the GuideConnect technology, using vehicle connectivity to mirror driverless operation. The technology allows two tractors to be connected using GPS and wireless communication and be driven by one driver[10].

It is worth mentioning that all these smart mobility technologies are optimally operating when they are connected not only with one another, but also with all the other machinery and facilities in the agricultural field. This is the realm of the Internet of Things (IoT). IoT devices are capable of bringing sensing, identification, and communication capabilities to any dumb machine. More IoT devices means more data can be collected by farmers, enabling remote control and surveillance of entire fields and farms.

HIGHLIGHTS FROM ONTARIO

KORECHI

Korechi Innovations Inc. specializes in the design of autonomous products for use in farms and turf-care. The company is affiliated with the Forge and the Innovation Factory at the McMaster Innovation Park in Hamilton, ON and the Spark Centre in Oshawa, ON. Korechi has developed RoamIO, an agricultural autonomous robot featuring an expandable platform that is compatible with different functional attachments.

Link: https://www.korechi.com/

INDRO ROBOTICS

InDro Robotics provides a full range of unmanned aerial vehicle solutions to monitor and collect data, and to provide a wide range of services to industries including agriculture. InDro Robotics is one of the few companies in Canada with Beyond Visual Line of Sight (BVLOS) certification. The company's Ontario office is in the town of Arnprior.

Link: https://indrorobotics.ca/

GPS ONTARIO

GPS Ontario, based in North Gower, ON, has been pioneering the precision agriculture industry since 2000. The company promotes complete farm solutions from hardware to data management. GPS Ontario works with SMEs to test, develop, and improve precision agriculture solutions across Canada and the USA.

Link: https://gpsontario.ca/

INTELLICULTURE

IntelliCulture is based in Kitchener, ON, and offers hardware equipment to capture data from farm equipment and broadcast it to their cloud database. The company utilizes this data for providing services such as farming equipment monitoring, operations & crop monitoring, and insightful predictions.

Link: https://www.intelliculture.ca/

Note: The companies highlighted above are only a few examples of the success stories in Ontario serving the agriculture industry.

CONCLUSIONS

In this report, we have shed light on the immense potential of smart mobility technologies for off-road use. In particular, we have focused on the use of these technologies in the agriculture industry. We have highlighted the current forces that are driving technological transformation in the industry. We have also delineated the various forms of smart mobility that can operate in agricultural fields and farms. This is while highlighting some of the major developments and opportunities that are brought to the agriculture industry by the use of these technologies.

It has also been noted in the report that, in order to augment the opportunities brought by smart mobility, the field/farm is better to be equipped with IoT devices to connect all parts together, bring intelligence to the various agricultural tasks, and provide farmers with the full remote control and monitoring experience. This is the key rule to join the "precision agriculture" and "smart farm" revolutions. It also implies that agricultural fields should embrace a robust communication infrastructure that can facilitate this digital transformation. This can be leveraged as a worthwhile opportunity to expand communication infrastructures and develop broadband networks, particularly in rural areas.

As they come to solve the major challenge of labour shortage in agriculture, smart mobility technologies also provide an opportunity to bring other - yet more attracting - associated jobs. With the need to remotely monitor, control, and maintain these machines, opportunities for a wider workforce with new skillsets that can be more appealing to the younger generations to get into the industry will emerge.

MEET THE AVIN TEAM

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ABOUT AVIN

The **Autonomous Vehicle Innovation Network (AVIN)** is a key component of Driving Prosperity, the Government of Ontario's initiative to ensure that the automotive sector remains competitive and continues to thrive. The Government of Ontario has committed $85 million in innovative programming to support research and development (R&D) funding, talent development, technology acceleration, business and technical support, and testing and demonstration sites. AVIN programs support small- and medium-sized enterprises (SMEs) to develop, test, and commercialize new automotive and transportation products and technologies, and cultivate the capacity of a province-wide network to drive future mobility solutions, reinforcing Ontario's position as a global leader.

AVIN, led by Ontario Centre of Innovation (OCI), is supported by the Government of Ontario's Ministry of Economic Development, Job Creation and Trade (MEDJCT) and Ministry of Transportation (MTO).

The initiative comprises five distinct programs and a central hub. The AVIN programs are:

- AV Research and Development Partnership Fund
- WinterTech
- Talent Development
- Demonstration Zone
- Regional Technology Development Sites

The AVIN Central Hub is the driving force behind the programming, province-wide coordination of activities and resources, and Ontario's push to lead in the future of the automotive and mobility sector globally. Led by a dedicated team, the Central Hub provides the following key functions:

- A focal point for all stakeholders across the province;

- A bridge for collaborative partnerships between industry, post-secondary institutions, broader public sector agencies, municipalities, and the government;

- A concierge for new entrants into Ontario's thriving ecosystem; and

- A hub that drives public education and thought leadership activities and raises awareness around the potential of automotive and mobility technologies and the opportunities for Ontario and for its partners.

AVIN has five objectives:

01 Foster the commercialization of Ontario-made advanced automotive technologies and smart mobility solutions

02 Showcase Ontario as the leader in the development, testing, piloting and adoption of the latest transportation and infrastructure technologies

03 Drive innovation and collaboration among the growing network of stakeholders at the convergence of automotive and technology

04 Leverage and retain Ontario's highly skilled talent

05 Harness Ontario's regional strengths and capabilities, and support its clusters of automotive and technology