ADVANCES IN CONNECTED & AUTONOMOUS VEHICLES

CURRENT STATE & FUTURE TRENDS

Information and Communications Technology Council and CAVCOE

March 2020

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EXECUTIVE SUMMARY

This paper is a complement to the white paper published originally by ICTC in 2017, entitled “Autonomous Vehicles and the Future of Work in Canada.” This work explores advancements in recent years, with a focus on technological infrastructure and inter-vehicle communication, and the broader impact of connected and autonomous vehicle technology including higher-level social implications of the technology for business, inclusion, accessibility, education and training.

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Introduction

Connected and autonomous vehicles (CAVs) are a fundamentally transformative technology that will impact virtually all facets of life—public, business and government. In the near future, CAVs will form the foundation of Smart City transportation, and their impact will be most effective when integrated with current and emerging urban transportation infrastructure.

An *autonomous vehicle* is described as using a "combination of sensors, controllers and onboard computers, along with sophisticated software, allowing the vehicle to control at least some driving functions, instead of a human driver." The degree of sophistication ranges from non-automated, which relies 100% on a human driver, to relying 100% on computers, with no provision for human intervention (except possibly an emergency stop button.) Transport Canada defines *connected vehicles* as "vehicles using different types of wireless communication technologies to communicate with their surroundings." *Connected and autonomous vehicles* (CAVs) use wireless networks and sensors to obtain relevant traffic and other vital information while driving and are controlled by sophisticated software. A critical enabler of CAV will be sufficiently high bandwidth, scalable communication infrastructure. Many new CAV advances presume such an existing network, typified by 5G infrastructure.

This work is meant to extend the ICTC paper, "*Autonomous Vehicles and the Future of Work in Canada*" (2017) in cooperation with CAVCOE. There is an emphasis on the integration of autonomous-vehicle technology in the environment through supporting communication infrastructure. This includes the higher-level social implications of the technology for business, inclusion, accessibility, education and training.

This paper targets two categories of readers: people in the private and public sectors, helping them better understand the trends and impacts of CAVs, and to prepare them for the CAV era; and people in the innovation ecosystem, helping those in research, development and testing understand CAV uses and impacts when the technology is deployed.

Connected & Autonomous Vehicle Technology

Many people think that *connected and autonomous vehicles* refer to self-driving cars, when in fact the ecosystem is much broader. The scope of CAV use cases includes the following:

- Passenger cars;
- Automated shuttles (with many in daily use around the world);
- Off-road heavy equipment for mining, agriculture, forestry and construction (a sector well-advanced in automation);
- Trucks;
- Non-passenger service vehicles for parcel delivery, garbage pick-up, snowplows, etc;
- Drones for goods delivery, police work, infrastructure inspections, etc. (larger airborne vehicles carrying passengers without a human pilot could be deployed within the next decade).

These applications generally use a common set of technologies:

- Batteries and electric drivetrain systems;
- Computing platforms, running software for real-time control, artificial intelligence, onboard infotainment, communications, cyber security;
- Communication infrastructure connectivity;
- Detect-and-avoid systems;
- Navigation systems, including Simultaneous Localization and Mapping (SLAM);
- Sensors, including vision systems, short-range and long-range radar, and Light Detection and Ranging (LiDAR).

The technologies for these use cases are similar but developed to different engineering specifications. (The scope of this report focuses primarily on passenger cars, but there is significant activity in the other areas.)

Connected and autonomous vehicles are a combination of Internet-of-Things (IoT) devices and networking capability to communicate with the surrounding physical and digital environment. Depending on the supported features, a connected vehicle may be able to communicate with the following:

- Vehicle occupants, occupants of other vehicles, connected devices, e.g. mobile phones; pedestrians;
- Internet-based applications;
- Security Credential Management System (SCMS), a message security solution for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication;
- Surrounding transportation physical infrastructure (this could include traffic signal controller, roadway infrastructure, traffic management centres—both local computing and cloud platforms).

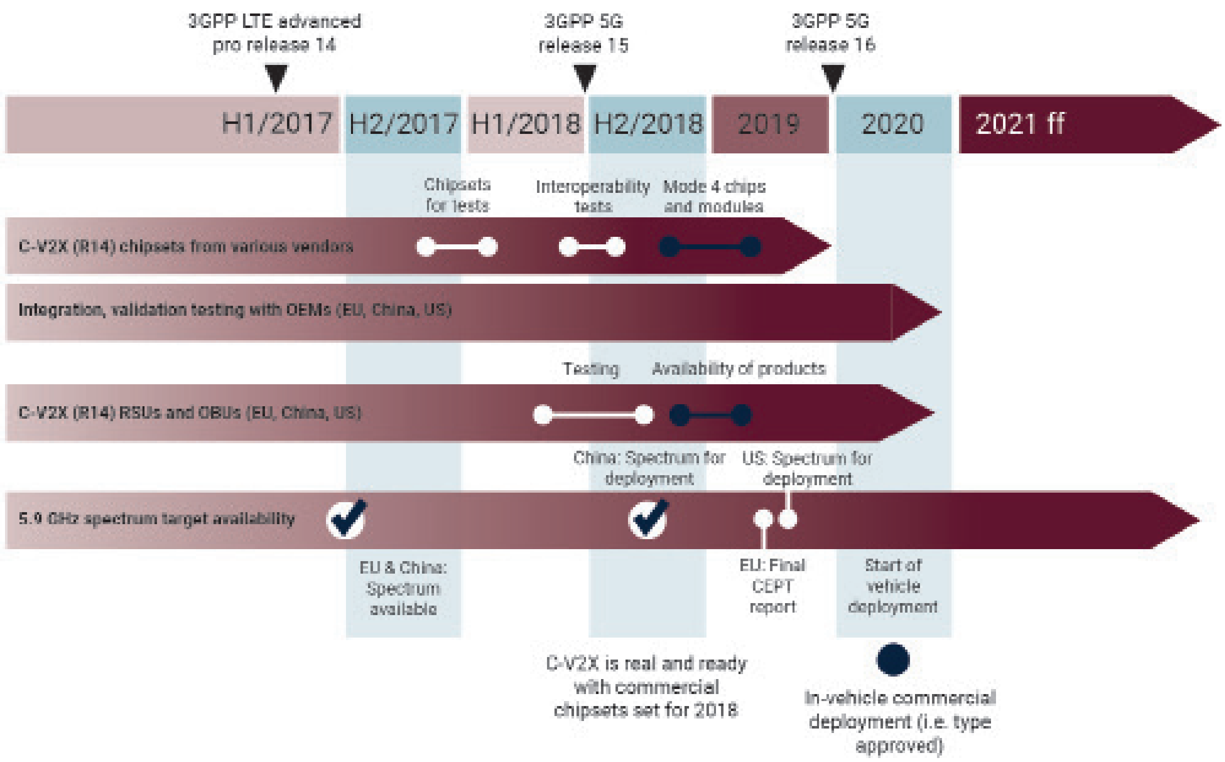

Figure 1: 5G Adoption Roadmap (Adapted from 5GAA)

CAVs will be able to communicate with each other in real-time, automatically transmitting data such as speed, position, direction, and provide alerts in the event of an imminent collision.

Technology Focus Areas

Recent advances in CAV research has focused heavily on the infrastructure and communication mechanisms that will enable connected autonomous vehicle control and interaction with its environment (Figure 1). This encompasses recognition of vehicle, civil structure, and human/animal obstacles. To support this capability, several key areas are relevant to the discussion:

- Communications, e.g., vehicle-to-vehicle, vehicle-to-infrastructure;
- Vehicle and infrastructure security;
- Intersection control;
- Collision-avoidance navigation;
- Pedestrian detection and protection.

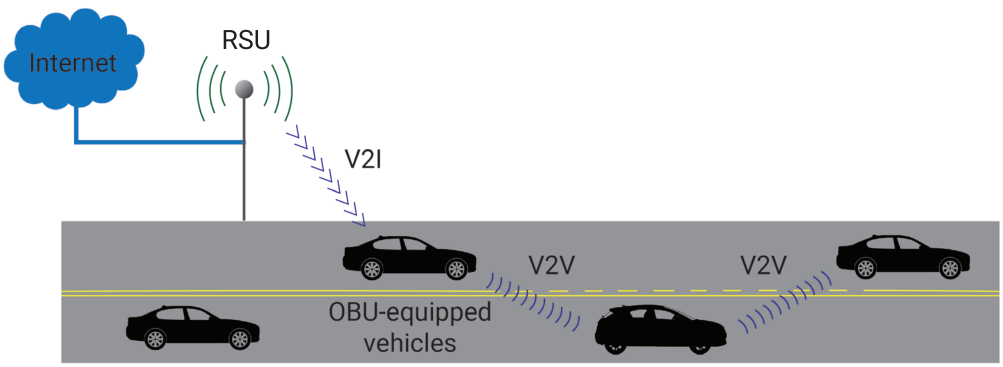

Figure 2: Dedicated short-range communications – DSRC (Adapted from original source: Ligo, A. and Peha, J.M., Spectrum Policies for Intelligent Transportation Systems (September 1, 2017). TPRC 45: The 45th Research Conference on Communication, Information and Internet Policy 2017)

Network Communications

CAVs require a stream of data to institute a proper protocol for roadway events, where information can originate from many sources, including roadside signs, radio stations, smartphone apps, etc.

Inter-vehicle communication allows for vehicles to exchange (possibly relay) information between one another about various environmental changes such as road hazards, weather conditions, traffic congestion, etc.[1] Aside from supporting autonomous mobility, the National Highway Traffic Safety Administration (NHSTA) , a part of the U.S. Department of Transportation, predicts that effectively applying vehicle-to-vehicle and vehicle-to-infrastructure communications could potentially reduce and/or eliminate up to 80% crashes of any type from non-impairment.[2] In CAV literature, there are two other

1 Fang, J., Xu, R., Yang, Y., Li, X., Zhang, S., Peng, X., Liu, X. (2017, October). Introduction and simulation of dedicated short range communication. In *2017 IEEE 5th International Symposium on Electromagnetic Compatibility (EMC-Beijing)* (pp. 1-10). IEEE.
2 NHTSA, 2017. Traffic Safety Facts 2015 Data-Pedestrians. NHTSA, Washington DC.

forms of vehicle communication included in intelligent transportation systems: *vehicle-to-pedestrian* (V2P) and *vehicle-to-network* (V2N). All these communication mechanisms are collectively referred to as *vehicle-to-everything* (V2X).

V2X heavily relies on wireless technologies. *Dedicated short-range communications* (DSRC) is a type of wireless technology developed for the automotive platform, specifically for use with CAV (Figure 2). DSRC is the pathway that allows CAVs to communicate with each other and infrastructure. The technology uses radio frequencies that lie in a range of the 5.9 GHz band, which is controlled and allocated in the U.S. by the Federal Communications Commission (FCC). DSRC has a communication range that extends a maximum of 500 feet in all weather conditions.[3] The IEEE standard for DSRC (IEEE 802.11p) has been implemented and endorsed by the U.S. Department of Transportation, in addition to various automotive manufacturers, including General Motors, Toyota, and Volkswagen.[4]

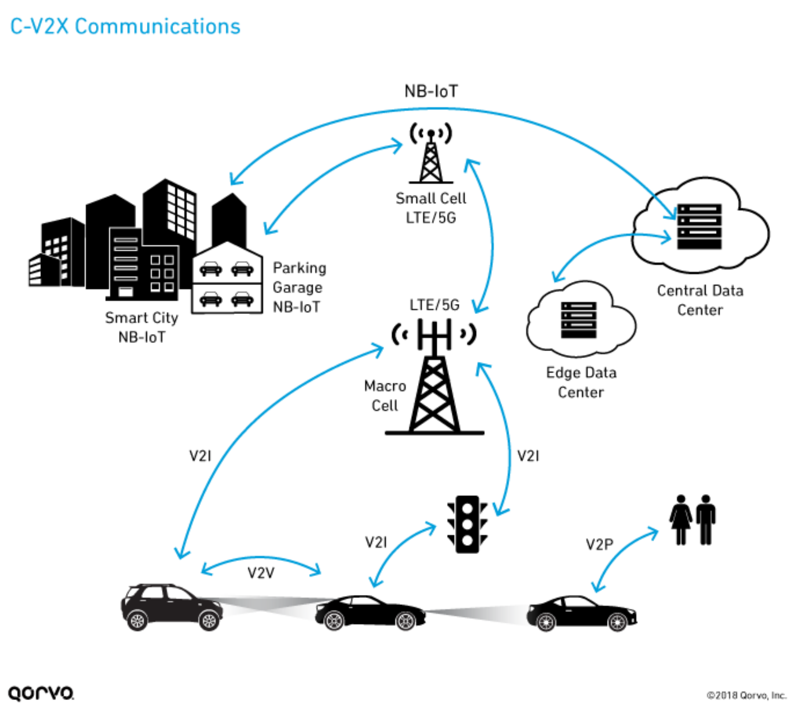

Figure 3: C-2VX infrastructure (Original source: Qorvo Inc.)

The DSRC system consists of two main hardware components: an onboard unit (OBU), referred to as onboard equipment (OBE); and the road-side unit (RSU).[5] Vehicle data is centrally aggregated by OBUs and can be used to moderate conditions in the environment, such as traffic congestion, a byproduct of human drivers.[6]

3 Lee, S., Lim, A. (2013). An empirical study on ad hoc performance of DSRC and Wi-Fi vehicular communications. *International Journal of Distributed Sensor Networks*, *9*(11), 482695.
4 Jiang, D., Delgrossi, L. (2008, May). IEEE 802.11 p: Towards an international standard for wireless access in vehicular environments. In *VTC Spring 2008-IEEE Vehicular Technology Conference* (pp. 2036-2040). IEEE.
5 Fang, J., Xu, R., Yang, Y., Li, X., Zhang, S., Peng, X., Liu, X. (2017, October). Introduction and simulation of dedicated short range communication. In *2017 IEEE 5th International Symposium on Electromagnetic Compatibility (EMC-Beijing)* (pp. 1-10). IEEE.
6 NHTSA, 2016. U.S. DOT Advances Deployment of Connected Vehicle Technology to Prevent Hundreds of Thousands of Crashes. NHTSA, Washington DC.

One significant limitation of DSRC-based V2X communications is its low scalability: in dense, closely proximate traffic, it is unable to provide satisfactory time-probabilistic characteristics.[7],[8] DSRC is engineered for fast transmission of short-range basic safety messages, and does support the high-bandwidth and low-latency communication channels required by more advanced V2X applications such as autonomous driving.

A competing high-capacity communication infrastructure is 5G Cellular V2X (C-V2X), with enabled products expected on the market after 2020 (Figure 3). In contrast to DSRC and 3GPP LTE, 5G C-V2X offers significantly higher throughput and reliability (99.999%), longer range (443-metre line of sight and 107-metre non-line of sight), and very low latency (10 milliseconds end-to-end and 1 milliseconds over-the-air).[9],[10] Similar to DSRC, 5G C-V2X provides direct messaging services among CAVs, allowing short-range communication when cellular towers are unavailable. 5G C-V2X will enable more advanced CAV features such as autonomous driving and highway platooning as compared to DSRC, which is essentially designed to support basic safety applications. Further, 5G C-V2X has significantly increased throughput and reliability and reduced latency. Industry stakeholders are evaluating 5G C-V2X in test environments to verify performance and compare it as an alternative to DSRC.

Environmental Situational Awareness

Traffic Lights and Intersection Navigation

Intersections and traffic lights are a fundamental nexus for vehicular accidents. The requirement for traffic lights at intersections diminishes in an environment supporting CAVs. Controlling an intersection involves two possible approaches: *centralized*, where the infrastructure is responsible for traffic decisions; or *de-centralized*, where inter-communicating CAVs themselves make traffic decisions. Research has been done on the use of artificial intelligence, where control of an isolated traffic intersection is accomplished via CAVs communicating with an autonomous agent.[11] A similar approach uses a more advanced reservation-based intersection controller for CAVs.[12] Automated control of the vehicle velocity can minimize the likelihood of two or more CAVs arriving at an intersection at the same time. Controlled CAV trajectories using *cooperative adaptive cruise control* (CACC) systems can avoid collisions and minimize delays at an isolated intersection.[13] A *centralized cooperative vehicle intersection control* (CVIC) algorithm has been proposed for CAV-only scenarios at isolated intersections without turning movements.[14]

7 Campolo, C., Vinel, A., Molinaro, A., Koucheryavy, Y. (2010). Modeling broadcasting in IEEE 802.11 p/WAVE vehicular networks. *IEEE Communications letters*, *15*(2), 199-201

8 Van Eenennaam, M., Wolterink, W. K., Karagiannis, G., Heijenk, G. (2009, October). Exploring the solution space of beaconing in VANETs. In *2009 IEEE Vehicular Networking Conference (VNC)* (pp. 1-8). IEEE.

9 Papathanassiou, A., Khoryaev, A. (2017). Cellular V2X as the essential enabler of superior global connected transportation services. *IEEE 5G Tech Focus*, *1*(2), 2017.

10 Sahin, T., Klugel, M., Zhou, C., Kellerer, W. (2018). Virtual cells for 5G V2X communications. *IEEE Communications Standards Magazine*, *2*(1), 22-28.

11 Dresner, K., Stone, P. (2008). A multiagent approach to autonomous intersection management. *Journal of artificial intelligence research*, *31*, 591-656.

12 Huang, S., Sadek, A. W., Zhao, Y. (2012). Assessing the mobility and environmental benefits of reservation-based intelligent intersections using an integrated simulator. *IEEE Transactions on Intelligent Transportation Systems*, *13*(3), 1201-1214.

13 Zohdy, I. H., Kamalanathsharma, R. K., Rakha, H. (2012, September). Intersection management for autonomous vehicles using iCACC. In *2012 15th international IEEE conference on intelligent transportation systems* (pp. 1109-1114). IEEE.

14 Lee, J., Park, B. (2012). Development and evaluation of a cooperative vehicle intersection control algorithm under the connected vehicles environment. *IEEE Transactions on Intelligent Transportation Systems*, *13*(1), 81-90.

Collision Avoidance

Vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-pedestrian communication capabilities enable critical situational awareness. Current accident avoidance relies on driver reaction, sensors, and the vehicle's collision-avoidance system; whether it is steering, braking, a combination of both, a CAV needs to be able to respond to similar circumstances. If vehicles can communicate with one another, their cooperation can serve as a possible means to reduce single car accidents or multiple car collisions.[15] In the event an autonomous vehicle has no possibility of avoiding a collision, the accident-bound vehicle could potentially relay a request to surrounding vehicles to adjust speed and position.

Significant research has been undertaken in the area of *Cooperative Collision Avoidance* (CCA), an approach that leverages V2X communication technology to create real-time collision avoidance algorithms and collaborative decision-making.[16] Equally applicable, in the case of environmental conditions such as 'No Line of Sight' (NLOS) or harsh weather, inter-vehicular communication safety capabilities can overcome the shortcomings of sensor safety systems that have been rendered ineffective.

Pedestrian Safety

Pedestrian safety poses a significant challenge to the acceptance of CAVs due to the high risk of injury and fatality in pedestrian/vehicular accidents. In the context of continuous advances in autonomous collision avoidance and the fundamental limits to human capabilities and reaction times, CAVs may prove to be safer for pedestrians than human operators. Pedestrian detection is one of the most intricate tasks for CAV technology to overcome. While basic pedestrian motion can be modelled by simplified rudimentary dynamics, human decision and action can be quite erratic and unpredictable, requiring CAV pedestrian detection to accommodate the many possibilities of pedestrian motion.

With the recent influx of technological advances in machine learning and computer vision, a crossover with some of these techniques into CAVs will be beneficial. In the domain of artificial intelligence, a form of machine learning called *convolutional neural networks* (CNNs) has been used to decide the necessary vehicular action based on predicting pedestrian movement.[17] A typical example is image segmentation and analysis for estimating direction and velocity of future movement. At their input layer, CNNs receive an encoding of an image and use forward and backward propagation of the values through neural layers to generate weights that compute a mapping to the output layer. Recent experiments testing CNN architectures for motion prediction of sequencing frames have generated recognition performance with an accuracy in the validation phase of 94%.[18] Although extensive testing remains to be conducted and many challenges remain, the integration of artificial intelligence (AI) in CAVs is promising.[19]

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15 Gelbal, S. Y., Zhu, S., Anantharaman, G. A., Guvenc, B. A., Guvenc, L. (2019). *Cooperative Collision Avoidance in a Connected Vehicle Environment* (No. 2019-01-0488). SAE Technical Paper.

16 Hafner, M. R., Cunningham, D., Caminiti, L., Del Vecchio, D. (2013). Cooperative collision avoidance at intersections: Algorithms and experiments. *IEEE Transactions on Intelligent Transportation Systems*, *14*(3), 1162-1175.

17 Dominguez-Sanchez, A., Cazorla, M., Orts-Escolano, S. (2017). Pedestrian movement direction recognition using convolutional neural networks. *IEEE transactions on intelligent transportation systems*, *18*(12), 3540-3548.

18 Dominguez-Sanchez, A., Cazorla, M., Orts-Escolano, S. (2017). Pedestrian movement direction recognition using convolutional neural networks. *IEEE transactions on intelligent transportation systems*, *18*(12), 3540-3548.

19 Cunneen, M., Mullins, M., Murphy, F. (2019). Autonomous vehicles and embedded artificial intelligence: The challenges of framing machine driving decisions. *Applied Artificial Intelligence*, *33*(8), 706-731.

Security

As with any significant technological advancement, the need to secure the platform, communication channel, and data integrity are paramount. CAVs, like any computing and communication infrastructure platforms, are susceptible to two forms of attack: passive and active. In what follows we consider a few examples.

Passive attacks intercept information being transferred between a CAV and another communication point.

- For example, a CAV will broadcast a message containing verified velocity, location, a pseudonym, i.e., V_a or V_b , for the car, and other information to alert other vehicles nearby for safety purposes. Attackers may eavesdrop location information and car pseudonyms for initial selection of target car.[20]

Active attacks may consist of spoofing incorrect data, resending a previous message to obtain validated system keys, message modification of relevant data, or denying of service that prevents data transfer on an affected server where data transference is vital.

- GPS signals are susceptible to malicious jamming attempts because their power levels are low after long-distance attenuation. Using a jamming signal as an active attack, the GPS can be overpowered and rendered ineffective. The danger comes in the inability to determine when and where to stop without the locating signal.[21]
- An active attack may involve the intelligent transportation system as well as CAVs. Changing the distance in between autonomous vehicles can disrupt the flow of traffic or dramatically increase the chance of accidents.[22]

In the case of a Global Navigation Satellite System (GNSS) spoofing[23] attack, a vehicle can be misinformed by illegitimate broadcast signals mistakenly treated as trustworthy. Attackers can jam the original GNSS signal, causing the receiver to look for and acquire the incorrect signal instead of the proper signal.[24]

20 Yu, R., Zhang, Y., Gjessing, S., Xia, W., Yang, K. (2013). Toward Cloud-Based Vehicular Networks with Efficient Resource Management. *IEEE Network*.
21 Ozdemir, S. S., Aksoy, E. (2017, November). GPS jamming mitigation through Taguchi's optimization method. In *2017 25th Telecommunication Forum (TELFOR)* (pp. 1-4). IEEE.
22 Ghanavati, M., Chakravarthy, A., Menon, P. P. (2017). Analysis of automotive cyber-attacks on highways using partial differential equation models. *IEEE Transactions on Control of Network Systems*, *5*(4), 1775-1786.
23 Spoofing is the act of disguising a communication from an unknown source as being from a known, trusted source.
24 Psiaki, M. L., & Humphreys, T. E. (2016). GNSS spoofing and detection. *Proceedings of the IEEE*, *104*(6), 1258-1270.

Deployment Challenges

In a way, 2020 is like 1908, which saw the start of mass production of Model T Fords. While Henry Ford was undoubtedly a great inventor and entrepreneur, we doubt that even he could foresee the huge impact of commodity cars in the 20th Century. The changes affected individuals, cities, infrastructure, business and governments. It led to the creation of several great industries: automotive, oil, the expansion of the travel, restaurant, and accommodation industries.

In addition, throughout the century, there was a great focus on building infrastructure, not to mention far-reaching social ramifications. All told, the impact of CAVs in the 21st Century will be as broad and deep as was the car in the 20th century.

Canadian Readiness

In 2018, KPMG announced the *Autonomous Vehicles Readiness Index* to rank countries that are positioning themselves as autonomous-vehicle ready. The countries are ranked based on the four pillars that are integral to a country's capacity to adopt and integrate autonomous vehicles: policy and legislation, technology and innovation, infrastructure and consumer acceptance.[25]

In 2018, Canada was ranked 7th behind the Netherlands, Singapore, United States, Sweden, United Kingdom, and Germany. In 2019, Canada slipped five places to 12th place, behind the Netherlands, Singapore (these two countries retained their top ranking positions in the second year), Norway, the United States, Sweden, Finland, the Unite Kingdom, Germany, the United Arab Emirates, Japan, and New Zealand.

Based on KPMG's 2019 report, Canada's strengths include a high-quality workforce and strong government leadership. This leadership comes from different levels of government that see the potential benefits in economic productivity as well as social equity and commercial activity.[26] The report ranks Canada highest for government-funded CAV pilot initiatives, and second highest (behind the UK) for creating an open-data environment. Canada's main challenge is its sprawling geography and developing infrastructure for urban and remote locations. Canada's ranking drop is partly due to the low score on infrastructure, particularly the lack of 4G coverage and electric vehicle charging stations across the country.

25 https://assets.kpmg/content/dam/kpmg/xx/pdf/2018/01/avri.pdf

Impact on Society

The single greatest benefit of CAV deployment will be the reduction in the number of traffic deaths, injuries and collisions. Based on a U.S. study, 93% of traffic collisions are due partially or entirely to human error. It important to understand that CAVs will not completely eliminate accidents: a minimum of 7% of collisions would occur regardless of whether a human or computer is doing the driving. With full deployment of CAVs, it is forecast that the number of traffic deaths and injuries will be reduced by about 80% of 2020 levels. The important conclusion is that autonomous vehicles will be much safer than human drivers, but they will never be perfect.

Potentially the single greatest negative impact will be job displacement and ensuing social disruption.[27] Recently the introduction of ride sharing platforms such as Uber resulted in confrontations between conventional taxi drivers and providers of ride-share services. Another example is a proposal in Columbus, Ohio, to conduct a pilot of an automated shuttle service, leading to a threat by the transit union to go on strike.

This new era will not only lead to job displacement; it will also create many new jobs, especially in the technology sector, and will lead to significant changes in the workforce of the future. Consider vehicle service technicians currently trained in internal combustion engines, hydraulic systems, etc. In the near-future, they will need expertise in electric drivetrains, large battery systems, and onboard computer systems—as well as legacy systems. Canadian colleges and institutes and their associations are already exploring the important role they will play in developing the workforce of the future.

A key benefit of CAV deployment is the opportunity to improve mobility for seniors and people with disabilities. A 2019 report by ITS America explores this in considerable detail.[28] There will be a pressing need to develop standards to help ensure that CAVs are optimized for people who have handicaps.

One of the more controversial consequences of improved safety leads to this question: Who gets to drive? Consider the scenario in which future statistics confirm that computers are better and safer drivers than humans. This will force a conversation about banning human drivers. The question then becomes whether it is ethical to allow humans to continue driving—causing many deaths and injuries—when there is a safer and better technological alternative?

There will be many other socio-economic impacts. Here are several ways in which our lives will change in the next 10-20 years with the arrival of autonomous, connected, and electric vehicles:

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27 One example, 200 years ago, was the introduction of semi-autonomous spinning looms in northern England, leading to the rise of the original Luddites who resisted the change and went around smashing these new-fangled machines.

28 Bayless, S., Davidson, S. “Driverless Cars and Accessibility.” Intelligent Transportation Society of America (ITS), April 2019, https://static1.squarespace.com/static/596fb16003596e0fa70a232f/t/5c9bab319b747a61663ac9bc/1553705778370/ITSAmerica_Driverless+Cars+Accessiblity+Mobility_April2019.pdf.

- Gas stations and car service centres will start to disappear because of the arrival of electric vehicles, which need neither gas nor as much maintenance. In 2019, a gas station in Maryland converted entirely to an electric vehicle (EV) charging centre.
- Autonomous garbage collection vehicles will become more common.
- Small electric, pilotless aircraft will be introduced for short-haul flights on a downtown-to-downtown basis.
- Car ownership will decline as people will prefer the lower cost and improved convenience of driverless taxis, often referred as micro-transit or Mobility-as-a-Service (MaaS).
    - The business case for mass transit systems will also be affected because of micro-transit, as commuters opt for the convenience of door-to-door travel in a single mode. Ridership on mass transit systems and mass-transit revenues will decline. This trend has already started with the increasing popularity of ride-sharing services taking market share from mass transit.
- There will be fewer parking lots and parking garages because, with the deployment of driverless taxis, there will be a reduced need for parking.
- Virtually all departments at all levels of government will be impacted, including revenue, health-care, national security, industrial policies, urban planning, etc.
- Police forces and police budgets will be differently configured and allocated. A U.S. study shows that 53% of the public's interaction with police is due to traffic issues: collisions, speeding, distracted driving, running red lights and stop signs. Given that CAVs are safer (and more law abiding) there will be less of a need for traffic officers.
- Air quality in Canadian cities will improve because there will be far fewer internal combustion engines.

Finally, in this section on socio-economic issues, there is the question of the acceptance of CAVs by the general public. Studies conducted so far conclude the majority of people are uncomfortable with the idea of being in a driverless vehicle. However, let us do a thought experiment and return to the 1920s. Let us go to any train station in Canada, at that time, and conduct a survey of people who are getting on a train and ask them what they think about travelling between Canadian cities on one of those new-fangled flying machines. It is very likely that the majority of train passengers will say that they definitely prefer to stay on the ground. And yet, the extraordinary became ordinary in the early part of the 20th century.

Industry Milestones

2019 was a good year for Canada's CAV ecosystem and preparations for CAV deployment. In what follows we present a few highlights.

The Province of Ontario continues pursuing its goal of being a go-to destination for autonomous vehicle technologies. In 2017, Ontario invested $80 million over five years by launching an Autonomous Vehicle Innovation Network (AVIN). AVIN is a unique demonstration zone for researchers to hone their technology and test driverless cars in a wide range of traffic scenarios and weather conditions.[29] Ottawa was designated one of the six Regional Technology Development Sites (RTDS) funded by AVIN.[30] In May of 2019, the Ottawa L5 test track was opened. Supported by all three levels of government, L5 is a 1,660-acre site, with 16 kilometres of roads and several labs and buildings. The track is used for testing cybersecurity, operation in poor weather conditions, and interoperability between vehicles.[31]

The BlackBerry subsidiary, QNX, was one of the first businesses to open a testing hub for autonomous vehicles in Canada. In February 2019, it announced a $310.5 million investment in their Ottawa headquarters to develop CAV software and skills training.[32] BlackBerry QNX aims to develop new automated control systems, upgrade and secure communications in vehicles, improve vehicle safety by expanding its advanced driver assistance systems (ADAS), and develop and use concept cars as labs for technology and software development with this funding.[33] BlackBerry expects this investment will create 800 new jobs, 1,000 co-op spaces and maintain 300 positions in the next 10 years.[34] The Government of Canada's Strategic Innovation Fund committed an additional $40 million to this research and development.

CAV development and deployment in Alberta saw a gain in momentum, and there are CAV testing activities taking place in Edmonton, Calgary, Wetaskiwin and Beaumont, with support from the Government of Alberta and awareness campaigns.[35] In 2018, an electric autonomous (ELA) shuttle that seats up to twelve and travels at up to 12 km/hr was deployed in Edmonton and Calgary on select short, fixed routes. In 2019, a similar ELA was tested in Vancouver and Surrey, British Columbia for short periods of time. In May 2019, the City of Beaumont, Alberta, in partnership with Pacific Western Transportation, used ELA to showcase the latest in self-driving technology to the public. In May 2019—for the first time in Canada—ELA was integrated into regular mixed vehicle and pedestrian traffic along a kilometre-long stretch of one of Beaumont's main roads.[36]

The City of Toronto has started to adapt their urban planning and land-use strategies to make them CAV-ready. Toronto, in partnership with a number of local, provincial, national, and international organizations, has been preparing for the arrival of automated vehicles since 2015. In 2019, it released the Automated Vehicles Tactical Plan outlining an

29 https://news.ontario.ca/opo/en/2017/11/ontario-creating-opportunity-with-cars-of-the-future.html
30 https://www.avinhub.ca/regional-technology-development-sites/
31 https://electricautonomy.ca/2019/09/17/canadas-autonomous-vehicle-pilots/
32 https://business.financialpost.com/technology/blackberry-to-get-40m-in-federal-funds-to-support-self-driving-car-development
33 https://www.toronto.ca/legdocs/mmis/2019/ie/bgrd/backgroundfile-138569.pdf
34 https://pm.gc.ca/en/news/news-releases/2019/02/15/investment-automotive-innovation-make-vehicles-safer-and-create-jobs
35 http://www.mondaq.com/canada/x/822618/cycling+rail+road/The+Sensor+The+State+Of+Autonomous+Vehicles+In+Alberta
36 https://globalnews.ca/news/5285857/beaumont-autonomous-shuttle-no-driver/

actionable path forward to prepare Toronto for the introduction of CAVs on city streets, in public transit, and in the delivery of municipal services.[37]

Following the City of Hamilton's designation as one of the six Regional Technology Development Sites (RTDS) funded by Ontario's AVIN[38], Hamilton will open a public CAV test zone in the spring of 2020 for start-ups and local partners to test connected and autonomous systems and interactions. The main technology being tested will be artificial intelligence that analyzes the interactions between vehicles, pedestrians, and cyclists.[39]

The City of Toronto, Toronto Transit Commission (TTC), and Metrolinx are planning to launch an automated shuttle pilot project to connect local residents to and from the Rouge Hill GO station during rush hour. The service is planned to start in the fall of 2020 and run for six to 12 months. The service will use a small CAV shuttle on a route through residential streets not currently served by public transit.[40]

From 21 June to 4 August, 2019, Transdev and the City of Montreal partnered to deploy a public transportation service of autonomous shuttles in a dense urban environment and normal traffic. The 1.4 km route—connecting Montreal's Olympic Park metro station with the popular Maisonneuve Market—took approximately six minutes to cover, with vehicles reaching an average speed of 15 km/h. The EasyMile autonomous shuttles circulated in normal daily traffic conditions, crossing intersections equipped with intelligent traffic signals in communication with the shuttles.[41]

FPInnovations' transportation division PIT Group, Transport Canada, Auburn University, and Minimax Express Transportation collaborated to perform Canada's first ever on-road commercial vehicle platoon trial. The platooning tests took place between October 29 and November 2, 2019, on highways around Montreal, La Tuque, Trois-Rivières and Blainville, Quebec. The platoon consisted of two heavy-duty transport trucks, maintaining a minimum distance of 20 m between the trucks to allow a passenger vehicle to safely manoeuvre in between. The platoon travelled approximately 1000 km on highways with regular vehicle traffic. Human operators were in the cabs of both trucks the entire time, although future deployments will see only one human driver in the lead truck followed by automated trucks.[42]

37 https://www.toronto.ca/services-payments/streets-parking-transportation/automated-vehicles/automated-vehicles-background/
38 https://www.avinhub.ca/regional-technology-development-sites/
39 https://electricautonomy.ca/2019/09/17/canadas-autonomous-vehicle-pilots/
40 https://www.toronto.ca/services-payments/streets-parking-transportation/automated-vehicles/automated-vehicles-pilot-projects/automated-shuttle-trial/
41 http://transdev.ca/about/news/av-shuttle-pilot/
42 http://blog.fpinnovations.ca/blog/2018/11/28/pit-groups-truck-platooning-hits-the-road-in-a-canadian-first/

Impact on Business

It is an understatement to say CAVs will have a major impact on businesses. Global sales in CAVs will increase and are projected to reach US$172 billion by 2024.[43] Questions about when autonomous vehicles would finally enter the market have given way to forecasts about when fully-autonomous vehicles will become available, and which countries will be best positioned to usher in the CAV era.

One major example of the impact of CAVs is on the auto sector itself. Ford, GM and most OEMs agree that the auto sector will change more in the next five to 10 years than it has in the last 50 years. Many OEMs are looking to enter the *transportation services* business, speculating it will be more lucrative than building and selling cars.

The biggest winner is likely to be the information and communications technology (ICT) sector. The expectation is that the data harvested from a CAV is worth three to 10 times the value of the car itself; this includes both data about the vehicle occupants, data from outward-looking sensors that can see other vehicles, as well as people on the sidewalks. In a likely use case, this data can be combined with big data and processed using analytics to deliver micro-target advertising. Given the enormous amount of money generated by advertising on social media, data from CAVs will be an important feedstock for those platforms. This raises two significant policy issues: data ownership and privacy. The implications and solutions to these two issues are still being developed.

The insurance industry is actively evaluating its approach to the upcoming CAV era. The industry initiative is being led by the Insurance Bureau of Canada (IBC), which published a report on insurance and the future of mobility.[44] The recommendations include establishing a single insurance policy covering driver negligence and automated technology malfunctions to facilitate liability claims. The overall industry approach is still very much a work in progress, with this evolving as more truly driverless vehicles are deployed.

43 https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf
44 "Auto Insurance for Automated Vehicles: Preparing for the Future of Mobility". Insurance Bureau of Canada (IBC), 2019, http://assets.ibc.ca/Documents/The-Future/Automated-Vehicle-Report.pdf.

Other businesses that will see changes in the future include the following:

- Auto-body repair based on the expected reduction in collisions;
- Reduced need for driving schools as fewer people will be driving;
- Lawyers involved in car collision litigation will see a reduction in their revenue;
- Tow truck operations will see a reduction in their business;
- Transport truck drivers will also be in lower demand as automation handles the driving on the long-haul routes. However, this is one example of a change that would be very welcome in the industry because there is a significant and growing shortage of long-distance truck drivers.

It is important that businesses prepare for these changes by embracing the leading edge of disruption, rather than following. Our advice to businesses includes the following:

- Involve top management early because they will set the tone and the culture;
- Plan for the future despite the unknowns. The winners in 10 to 20 years will be those businesses that are prepared for the CAV era. Even an imperfect forecast of the future is significantly better than assuming the last 20 years will carry forward without change for the next 20 years;
- Review and revise your company's business plan for the CAV era, identifying which segments will benefit, which will be negatively affected, and which will be relatively unchanged;
- Inform your customers about your view of the future—partly to help them with their planning, and partly because it will brand your company as being on the leading edge of this very disruptive technology.

Regulating Connected and Autonomous Vehicles

An important component to preparing for the CAV era is—of course—adjusting the regulations.

Technology companies, academic and research institutions, automakers and manufacturers of parts, systems, equipment or components for automated driving systems will all play important roles in the future of CAVs deployment. However, this future depends on government regulations for sharing public roads in Canada with CAVs.

Globally, only a limited number of countries have introduced regulations for the classification, testing, and deployment of autonomous vehicles. For the next few years, government policy and regulation will be playing catch-up, reacting to new and improved technologies, and revisiting the balance between public safety and safeguarding voluminous amounts of privately held technical data.[45]

KPMG's 2019 report ranked Canada 12th in the world for CAV-ready policy and legislation, thanks to the government's extension of the regulations on CAVs in January 2019. The report notes that countries that are performing well on innovation, technology and infrastructure metrics are lagging in terms of upgraded policies and regulations.

For the most part, the federal government of Canada is responsible for establishing national policies and regulations to define and enforce vehicle safety standards. Provincial and territorial governments have jurisdiction over vehicle operation, including a Highway Traffic Act, drivers' licences, vehicle registration, automobile insurance, and roadway maintenance.

Provincial Regulations

In 2016, Ontario was the first province in Canada to develop a 10-year pilot regulatory framework for testing autonomous vehicles: Ontario's Automated Vehicle Pilot Program. Last year, the Province of Ontario lifted some regulatory bans and expanded the rules.

As of January 2019, completely driverless vehicles (Level 5)[46] may be tested on public roads in Ontario. Pilot participants can test driverless vehicles on Ontario's roads under strict conditions that will ensure tests are conducted in safe and controlled

45 http://www.mondaq.com/canada/x/777976/cycling+rail+road/The+Sensor+Legal+Insights+into+Autonomous+Vehicles
46 Refers to Full Automation: Vehicle is capable of being completely driverless. Full-time automated driving in all conditions without need for a human driver.

environments. Pilot participants must have either a passenger on board or a remote operator monitoring the vehicle's operations, vehicle signage requirements must be met, and local authorities must be alerted.[47] Ontario has granted permission to pilot tests for seven companies, including Blackberry QNX, Continental, Magna, and Uber.

The Ontario rules now also permit businesses to sell CAVs equipped with SAE Level 3 technology (even though SAE Level 3 vehicles are not available for purchase yet). SAE Level 3 refers to conditional automation, based on the Society of Automotive Engineers universal classification system. CAVs with SAE Level 3 manage most safety-critical driving functions, but the driver must always be ready to take control of the vehicle. Level 3 CAVs are no longer restricted to registered pilot participants only. These amendments to the regulations illustrate that Ontario is supportive of more rapid adoption and use of CAVs on Ontario roads.

Lastly, pilot participants can now test "platooning" technology under strict conditions in Ontario. Platooning refers to several vehicles in a short convoy with a single human driver in the first vehicle and connectivity technology to enable driverless vehicles to follow in a convoy. This change enables trucks to operate with the potential for greater fuel efficiency and ease of operation[48] and is viewed as a strategy to alleviate the national shortage of long-distance truck drivers.

National Regulations

In early 2019, Transport Canada released two important documents: the Safety Assessment for Automated Driving systems in Canada[49] and Canada's Safety Framework for Automated and Connected Vehicles[50]. These two reports aim to provide an overview of Canada's current legislation and regulatory standards on CAV that will help the industry accelerate the safe introduction of automated and connected vehicles on Canadian roads. However, Canada is still lacking the federal standards for even low levels of automation (SAE levels 0-2), such as active driving features or collision avoidance features on vehicles that are already available to Canadian consumers. The lack of such standards is even highlighted in the recent Canada's Safety Framework for Automated and Connected Vehicles document: "While Transport Canada regulates some advanced safety features, such as advanced lighting technologies, mandatory back-up cameras and electronic stability control systems, there are no standards at this time that deal specifically with automation features, such as automatic emergency braking, automated steering systems and adaptive cruise control."[51]

In the absence of formal regulations and to assist the safe development and deployment of CAVs on Canadian roads, Transport Canada has published several documents outlining guidelines and tools for manufacturers to follow. As an example, in 2018, Transport Canada and the Canadian Council of Motor Transport Administrators issued a report entitled, "Testing Highly Automated Vehicles in Canada: The Guidelines for Trial Organizations." Its aim is to help clarify minimum standards for operators and the various roles and responsibilities of federal, provincial and territorial levels of government involved in facilitating trials.[52]

47 https://news.ontario.ca/mto/en/2019/01/changes-to-ontarios-automated-vehicle-pilot.html
48 https://news.ontario.ca/mto/en/2019/01/changes-to-ontarios-automated-vehicle-pilot.html
49 https://www.tc.gc.ca/en/services/road/documents/tc_safety_assessment_for_ads-s.pdf
50 https://www.tc.gc.ca/en/services/road/documents/tc_safety_framework_for_acv-s.pdf
51 https://www.tc.gc.ca/en/services/road/documents/tc_safety_framework_for_acv-s.pdf
52 https://www.tc.gc.ca/en/services/road/safety-standards-vehicles-tires-child-car-seats/testing-highly-automated-vehicles-canada.html

Conclusions

The future of transportation will be exciting and challenging, where connected and autonomous vehicles will lead to huge disruptive changes in personal lives and in the private and public sectors. Apart from the key benefit that machines will be better and safer drivers than humans, there are many business opportunities in the years ahead. One government policy expert has noted that there will be impacts on virtually all departments in all three levels of government.

These changes have already started, although slowly. By 2030, our lives, cities, society and infrastructure will be significantly different.

Connected vehicles will help cities and states reduce traffic congestion, improve fuel efficiency and improve safety for passengers and pedestrians. The U.S. National Highway Traffic Safety Administration predicts that effectively applying vehicle-to-vehicle and vehicle-to-infrastructure communications could potentially reduce and/or eliminate up to 80% of collisions.[53]

The key to successful implementation and adoption of CAVs will come from effective network infrastructure, specifically fifth-generation wireless technology for digital cellular networks (5G). Beyond communication, the use of artificial intelligence will be essential for the vehicle control, sensor data analysis, and predicting driving scenarios in the environment before they occur.

The social implications of CAV, especially with respect to its integration with Smart Cities, will be revolutionary. It is essential the Canadian government compete with global partners to stay up-to-date with regulatory aspects of autonomous transportation.

53 “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application”. NHTSA, 2017, https://www.nhtsa.gov/document/readiness-v2v-technology-application.

Recommendations

1. The Government of Canada should accelerate its work on planning for the deployment of CAVs. The federal government has done an excellent job of supporting and advocating for the innovation sector. There is also the excellent work being performed by the Federal Government's Vehicle of the Future Advisory Group. However, compared to work in the UK and other countries, more needs to be done. For example, ZENZIC, a UK QUANGO, released in late 2019, a roadmap to have thousands of CAVs on UK roads by 2030. The extensive research, consultations, and workshops led to a roadmap with over 500 milestones for the next 10 years. A similar initiative is required on a national basis in Canada.

2. At the provincial level, Ontario is in a similar situation: very strong support for innovation in the technology and auto sectors, but not enough is being done to prepare for the arrival of CAVs. We recommend that this planning focus not only on transportation and transit but also on the broader, government-wide issues.

3. Apart from Ontario, other provinces are generally not as involved in CAV innovation and preparedness. We recommend that they become more involved.

4. At the municipal level, our recommendations depend upon the current status of CAV-related development. Toronto, for example is doing an excellent job of preparing for the CAV era. Some examples are mentioned above. Ottawa, Kitchener-Waterloo, and Stratford are all excellent centres for innovation, research, development and testing. However, we recommend that they also focus on planning for the arrival of CAVs. We recommend that other cities examine the role of CAVs over the next 10 to 20 years, both in terms of the potential economic benefits and their incorporation into Transportation and Transit Master Plans.

5. In the last few years, Canada has performed world-class innovation in the CAV ecosystem. Research, development and testing is not only important from a technical perspective, but it is increasingly being seen by all three levels of government as key to economic development. This ongoing work includes connected vehicles (5G and DSRC), automated vehicle hardware and software, cyber-security, adapting the technology for severe winters, testing on dedicated facilities and public roads, smart communities and smart roads, and many other related areas. We recommend that this innovation by the private and public sectors and academia continue, be encouraged, and be accelerated to the extent that budgets permit.

6. Finally, we recommend a more substantial education program for the general public. As we have described above, most people in Canada will be personally impacted by the arrival of CAVs in 2020. As with the arrival of the first mass-produced cars in 1908, the impact of CAVs on the public will generally be very beneficial but not entirely. A communications program would be very worthwhile, and one of its objectives should be to better manage expectations. Specifically, all stakeholders need to hear the messaging that CAV s will be much safer than human drivers but will not be perfect. There will continue to be collisions, deaths and injuries but at a much lower level.

About the Authors

Maryna Ivus is a Senior Research Analyst at the Information Communications and Technology council. She has spent several years working as a researcher and enjoys approaching complex research challenges through both a qualitative and quantitative lens. She is committed to using her research to help strengthen Canada's digital advantage in a global inclusive economy. Maryna was involved in researching and writing a number of reports for ICTC, covering topics like the impact of emerging technologies on the labour market, digital economy trends and many others. Motivated by the potential benefits technology can offer to society, and concerns of fairness, accountability and inclusivity, she seeks to continue to contribute to critical conversations surrounding the development of Canada's growing digital economy. Maryna holds a Masters of Economics degree from the University of New Brunswick, graduated near the top of her class and was asked to be a lecturer in other university economics classes.

Barrie Kirk, P.Eng. has been a consultant since 1982 specializing in the management and engineering aspects of emerging technologies. His work over the last few years has focused on connected and automated vehicles (CAVs). He is a well-known keynote speaker, broadcaster and consultant on this subject. Mr. Kirk's current responsibilities include: Executive Director, CAVCOE; CEO, Canadian Automated Snow Plow Initiative (CASPI); Organizing Committee, CAV Canada 2020 Conference; Transport Canada / ISED's Vehicle of the Future Advisory Group; CSA Group's CAV Advisory Council; and the Canadian Advisory Committee, ISO / TC204 (Intelligent Transport Systems). Over his career, he has worked in the technology industries in Canada, the U.K., and the U.S., including senior management positions at Telesat Enterprises and Lapp-Hancock, and management positions at BNR, Nortel, and Bell Canada. Mr. Kirk holds a B.Sc. (Honours) in Electrical Engineering (Telecommunications and Electronics) from Coventry University, U.K. and is a Professional Engineer.

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Appendix A: Skills and Education

Recent advances in connected autonomous vehicle (CAV) research has focused heavily on the infrastructure and communication mechanisms that will enable connected autonomous vehicle control and interaction with its environment. The skills required to work in these areas cover a technical spectrum as broad as the engineering disciplines that are the foundation of the technologies. It is insufficient to talk simply of development skills: rather, each area dictates a specialization within a specific area and programming is simply a tool for expressing a solution.

For instance, consider a cybersecurity specialist in the AV/CAV field: tasks in this domain require expertise in network infrastructure (protocols, standards); programming (Java, C, C++); electrical engineering (digital signal processing, network signaling); real-time programming (algorithm optimization, hardware programming, etc.).

Many other core skills will be required, with a technical focus on the relevant application domain, be it driver UX, sensor array control, high-speed networking, etc.:

- Artificial intelligence;
- Data science, analytics;
- Visualization, human-computer interfaces, graphic design;
- Networking engineering, both software and hardware.