Choosing Canada's Automotive Future

The Expert Panel on Connected and Autonomous Vehicles and Shared Mobility

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The project that is the subject of this report was undertaken with the approval of the Board of Directors of the Council of Canadian Academies (CCA). Board members are drawn from the Royal Society of Canada (RSC), the Canadian Academy of Engineering (CAE), and the Canadian Academy of Health Sciences (CAHS), as well as from the general public. The members of the expert panel responsible for the report were selected by the CCA for their special competencies and with regard for appropriate balance.

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The Expert Panel on Connected and Autonomous Vehicles and Shared Mobility

Under the guidance of its Scientific Advisory Committee, Board of Directors, and founding Academies, the CCA assembled The Expert Panel on Connected and Autonomous Vehicles and Shared Mobility to undertake this project. Each expert was selected for their expertise, experience, and demonstrated leadership in fields relevant to this project.

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Message from the President and CEO

Connected, autonomous, shared, and electric vehicles could have a profound impact on society. They have the potential to improve vehicle and road safety, reduce travel time, reduce emissions, increase people's mobility choices, and change the way people interact and move, among other benefits. They showcase science and engineering at its best.

While their appearance on public roads in Canada may seem inevitable, there remains uncertainty about the timing of their arrival and their widespread adoption and acceptance. The planning and policy decisions made today will affect the impact of these vehicles on society tomorrow. There are opportunities and challenges throughout industry, across governments, and for the people of Canada.

To better understand how the decisions today will shape how connected and autonomous vehicles and shared mobility services will operate in Canada, the Minister of Innovation, Science and Economic Development Canada (ISED) asked the Council of Canadian Academies (CCA) to examine this topic in detail.

A 12-member Expert Panel was convened including those with expertise and experience in computer, electrical, civil and mechanical engineering, environmental science, computer science, kinesiology, political science, geography, and ethics, along with automotive, information and communication technologies (ICTs), and shared mobility industries. The Panel drew on diverse sources of quantitative and qualitative data, identified and considered relevant evidence, including literature from peer-reviewed publications, reports, publicly available government documents, and grey literature. This was supplemented with interviews with experts from industry and stakeholder groups to obtain additional insights.

The final report, *Choosing Canada's Automotive Future*, identifies potential impacts for policy areas critical to connected and autonomous vehicle development and diffusion: industry, including the automotive, ICT, and insurance sectors; data, privacy, and cybersecurity; mobility and urban planning; the environment; and the safety and well-being of people in Canada. It provides a set of findings and conclusions that can help shape the future.

I extend my thanks to Panel Chair Jeannette Montufar and the entire Expert Panel. As with every CCA assessment, the CCA Board of Directors, Scientific Advisory Committee, and the three founding Academies — the Royal Society of Canada, the Canadian Academy of Engineering, and the Canadian Academy of Health Sciences — provided critical guidance and oversight during the assessment process. I thank them for their support.

Eric M. Meslin, PhD, FRSC, FCAHS
President and CEO, Council of Canadian Academies

Message from the Chair

Virtually every new vehicle produced today has an advanced driving assistance system and some level of connectivity. It's possible to purchase a car that will parallel park itself, automatically brake when it anticipates a collision, stay centred in a lane, and handle most of the task of highway driving. There are currently autonomous delivery vehicles transporting people and goods on roads, and prototypes of low-speed autonomous shuttles and robo-taxis being tested today. But a scenario where fully autonomous vehicles are the default and not the exception is still many years into the future.

These technologies will continue to evolve, connecting more vehicles to each other, to infrastructure, and to other users on the road. Increased automation and advanced sensors could improve safety by reducing the number of collisions caused by human error. Connected and autonomous vehicles and shared mobility have the potential to make transportation more environmentally friendly, safe, and accessible. The Panel focused its discussions on impacts by making the working assumption that technology is moving towards a future in which vehicles will not only be connected and autonomous, but also shared and electric.

The long-term promise of future mobility is in connected, autonomous, shared, and electric vehicles that can supply on-demand, convenient, accessible, and affordable transportation to all people in all regions of Canada. But it's difficult to predict when, how, and even if these benefits will be fully realized. Reaching these goals will require overcoming significant technical and societal challenges and will depend on how industry, Canadians, and governments respond today to the potential challenges and opportunities. Planning and policy decisions related to public transit, ride sharing, and active transportation made today will affect how, when, and where these vehicles are used in Canada in the next 10, 20, and 50 years.

The current pace of technological change makes projecting into the future difficult. To minimize this uncertainty, the Panel adopted a 10-year outlook, which also aligns with the federal government's priorities for policy planning and decision-making. The Panel also recognizes that the COVID-19 pandemic will have significant consequences for the vehicle industry, on Canadians' mobility choices, and on government policy around these vehicles, not just now, but also over the next 10 years.

I extend my sincere thanks to each of the panellists who lent their time and expertise to this project. Their contributions have helped to produce an accurate and compelling report. I would also like to thank the reviewers, whose thoughtful input helped to strengthen this report. On behalf of the Panel members, I extend our sincere thanks to the CCA staff for bringing us together to tackle this important question and for supporting our work through every step of the process.

We are confident this report captures the wide range of potential impacts of connected, autonomous, shared, and electric vehicles, on industry, privacy and cybersecurity, urban planning, the environment, and the safety and well-being of people in Canada.

Jeannette Montufar, PhD, P.Eng., FCAE
Chair, The Expert Panel on Connected and Autonomous Vehicles and Shared Mobility

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Peer Review

This report was reviewed in draft form by a group of reviewers selected by the CCA for their diverse perspectives and areas of expertise. The reviewers assessed the objectivity and quality of the report. Their confidential submissions were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the findings, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the CCA.

The CCA wishes to thank the following individuals for their review of this report:

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The peer review process was monitored on behalf of the CCA's Board of Directors and Scientific Advisory Committee by **Chris MacDonald,** Director, Ted Rogers Leadership Centre, Ryerson University. The role of the peer review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the peer reviewers. The Board of the CCA authorizes public release of an expert panel report only after the peer review monitor confirms that the CCA's report review requirements have been satisfied. The CCA thanks Dr. MacDonald for his diligent contribution as peer review monitor.

Main Findings

Connected and autonomous vehicles (CAVs) and shared mobility offer the promise of a more effective, efficient, and integrated transportation system with reduced congestion, fewer collisions, and greater mobility options. CAVs could lead to improved equity and accessibility in transportation for older adults, children and youth, people with limited mobility, and those living in areas underserved by public transportation. These vehicles present new business opportunities for industry including software development, shared mobility services, infotainment, and infrastructure. Canada's strengths in automotive manufacturing and information and communications technology (ICT), position it well to take advantage of new and existing opportunities in these areas.

Governments, industry, and people in Canada are making decisions today that will shape how CAVs and shared mobility services will operate on Canadian roads. To this end, a multidisciplinary Expert Panel assembled by the CCA examined impacts in policy areas critical to CAV development and diffusion: industry, including the automotive, ICT, and insurance sectors; data, privacy, and cybersecurity; mobility and urban planning; the environment; and the safety and well-being of people in Canada. The Panel notes that vehicle electrification is a current trend that will continue under growing political, societal, and environmental pressures to reduce our reliance on fossil fuels. The high initial costs of autonomous vehicles, coupled with a growing mobility service sector, has led to the prediction that early commercial availability of CAVs will largely be through some type of shared mobility service. To focus its efforts, the Panel examined potential impacts in the next 10 years. They also worked under the assumption that connected and autonomous vehicles would most likely be shared and electric (i.e., CASE vehicles: Connected, autonomous, shared and electric vehicles).

CASE vehicle technology is rapidly evolving; it is reasonable to expect some limited applications and impacts over the next 10 years

Connectivity and driving automation systems (DAS), common in new vehicles being built and sold to consumers today, will continue to improve over the next 10 years. As communication networks become more integrated and ubiquitous, vehicles will become more connected to other vehicles, infrastructure, and other road users through vehicle components, smartphones, and wearable devices. This connectivity will be used to improve the transportation experience through traffic management, navigation features, ordering and payment systems, infotainment, and safety features, among other uses. Similarly, DAS will continue to be enhanced with more automation and improved sensors, promising to improve road safety by reducing the number of collisions resulting from human error.

Vehicular technologies are progressing towards complete automation; eventually, vehicles may be able to drive themselves in all conditions, though this level of automation, if achievable, is far in the future. However, autonomous vehicles with operational limits are possible today. Already, low-speed autonomous shuttles, robo-taxis, and autonomous delivery vehicles are transporting people and goods on roads in North America, as prototypes and in testing programs. In their earliest commercial iterations, these vehicles will be remotely monitored, operated at low speeds, and limited in their ability to travel outside specific geographic locations (e.g., on a campus) or confined to a particular route (e.g., from airport terminal to parking and back). Anticipated improvements in connectivity, artificial intelligence (AI), and sensor technology will allow these vehicles to operate safely and efficiently under a wider range of circumstances by coordinating their behaviour with other vehicles, communicating with traffic infrastructure, and accessing real-time updates on traffic and road conditions, navigation maps, and software.

The full potential of CASE vehicles is unlikely to be realized for several decades

The long-term promise of future mobility is in CASE vehicles that can supply on-demand, convenient, accessible, and affordable transportation to all people in all regions of Canada. Realizing these goals will require overcoming significant technical and societal challenges, the likelihood of which are debated because of the inherent uncertainty associated with technological change. While the results of the limited operations of robo-taxis and low-speed shuttles are promising when it comes to technological developments, achieving full automation — that is, a vehicle that can drive anywhere, anytime, without human intervention — is still widely considered to be out of reach with current technology. Furthermore, it is not yet clear whether the advances in AI that are required for full automation are achievable in the near- to medium-term. Nonetheless, CASE technologies, in their various stages of development, are quickly making appearances in vehicles on roads in Canada, bringing both challenges and opportunities for industry and governments in Canada.

Early impacts of CASE vehicles on people in Canada will be concentrated in urban areas

The timing and approach to deploying CASE vehicles on Canadian roads will not be evenly distributed across the country, nor will all regions necessarily experience similar outcomes. Mobility policy, public-private partnerships, infrastructure investments, and provincial, territorial, and municipal regulations will shape the eventual integration of CASE vehicles in different regions in Canada. For example, shared mobility requires some minimum population density to operate efficiently, connected vehicles require network capacity, and electric vehicles require charging infrastructure. Thus, the majority of deployment, be it in testing or in commercial operations, will likely be limited to select urban (or suburban) areas, at least within the next decade. There also may be opportunities for smaller municipalities to address mobility needs with new technologies (e.g., low-speed driverless shuttles). However, cost savings from automated driving are tempered by the increases in capital and acquisition costs of these vehicles. Government interventions brought electricity and telephones to rural areas; similar interventions may be necessary to ensure CASE vehicle benefits are fairly distributed across Canada.

CASE vehicles present both opportunities and challenges for industry in Canada

The mass production and manufacturing of CASE vehicles is likely to fundamentally change the industrial structure of Canada’s automotive sector, as the vertically integrated motor vehicle and parts manufacturing industry merges with the networked and more horizontal structure of the ICT sector. CASE vehicles create opportunities for research and development (R&D) expansion in the automotive industry, though is it unclear whether Canada will be able to attract and maintain R&D commitments from both international and domestic firms without a sustained, coordinated, and large-scale public policy regime to support such activities.

Despite the profound impacts of electrification and enhanced ICT content in future vehicles, CASE vehicles will still require parts and components suppliers that are currently integral to Canada’s automotive manufacturing sector. For Canada, the impact of the shift to CASE vehicles will be influenced by how well automotive companies adapt to evolving production networks, and whether production mandates are secured for new technologies and vehicle assembly in Canada, which have historically required government support. This is further complicated by uncertainty over the potential impact of new trade agreements.

The shift to CASE vehicle production networks will also open many new opportunities in both manufacturing (e.g., battery production and recycling, AI, and sensor technologies) and services (e.g., fleet management and customer services, gaming, infotainment, financial services, and insurance products). For ICT companies based in Canada to take advantage of these opportunities, they will need to overcome the known challenges associated with bringing new innovative products to the global market, as well as specific challenges associated with accessing the global ICT production networks linked to CASE vehicle production. ICT companies will also have to integrate with the different timelines, standards, and expectations of the automotive sector, and vice versa, in order to sustain lasting relationships.

Proactive urban management will help ensure the benefits of CASE vehicles are achievable

The appearance of CASE vehicles on roads in Canada in the next 10 years and beyond will implicate all levels of government across a range of state functions, and involve municipal planners, transit authorities, and civil engineers, among others. Actively planning for the potential impacts of vehicles with higher levels of automation, connectivity, electrification, and shared use will be important for urban centres already struggling with congestion, curbside management, and the balance between commercial and personal vehicles. This preparation includes considerations of infrastructure upgrades and maintenance, electrical and communication network demands, and street design changes to cope with the increased demand for pick-up and drop-off locations for shared vehicles and autonomous delivery services.

The potential for higher travel demands, greater accessibility, and empty vehicles travelling autonomously to pick up passengers or deliver goods may increase the overall vehicle kilometres travelled on city streets and add to issues of congestion and traffic management. CASE vehicles could either complement or detract from public transit ridership, depending upon the decisions and actions of both the public as well as city planners and transit authorities. Mobility planning must necessarily consider multi-modal travel (i.e., pedestrian and cycling infrastructure, public transit systems, commercial vehicles, and personal vehicles), and decisions made today will influence their convenience, costs, and usage in the future. Reductions in congestion may require policy tools such as introducing congestion pricing, incentivizing ride sharing, and prioritizing public transit and active transportation infrastructure, all of which are independent of advancements in vehicle technology. Proactive management will help to ensure that CASE vehicles improve mobility rather than add to current challenges.

The development of CASE vehicle technology will outpace product liability and insurance laws and regulations in the next 10 years

New or amended legislation will likely be required in order to address liability in vehicle collisions that involve increasingly complex automated driving systems. Over the longer term, if CASE vehicles reduce personal vehicle ownership as ride and car sharing become more common, there could be a reduced demand for personal auto insurance and an increased demand for commercial auto insurance. CASE vehicles may eventually cause the consolidation of insurance companies, and new, non-traditional competitors may enter and disrupt the industry. Usage-based insurance costs will likely increase as telematics data are used to distinguish driver liability from vehicle liability. Drivers may face new liability risks in failing to follow appropriate protocols for a given level of automation or for failure to update vehicle software. Analysis of telematics data may allow for the development of split risk profiles (i.e., between automated driving systems and human drivers), though it is not yet clear how liability, fault, and costs will be shared in situations where both driver error and vehicle technology failures contribute to a collision.

The potential environmental and health benefits of CASE vehicles depend more on mobility behaviours than technological advances

Mobility behaviours that lower the total vehicle kilometres travelled (e.g., ride sharing, active transportation, public transit) are essential to improving air quality, congestion, and public health in Canada. CASE vehicle technology can help to improve air quality and lower greenhouse gas emissions; however, CASE vehicles may also lead to worse air quality, even with increasing electrification, if they induce higher travel demand and create more pollution from tire and brake wear. CASE vehicles may provide health benefits by reducing injuries and fatalities from vehicle collisions, but only with robust safety standards for the use of these vehicles, which will require significant effort in the collection, pooling, and analysis of driving and collision data from both automated driving systems and human drivers. CASE vehicles may also improve safety for other road users, such as pedestrians and cyclists, potentially encouraging active transportation; however, they may also decrease physical activity should autonomous vehicle trips replace trips otherwise made by walking or cycling. Gaining the societal and environmental benefits of CASE vehicles will require more than new technologies; it will also require sustained and coordinated efforts among governments, stakeholders, and the public to shift mobility behaviours, design efficient multi-modal mobility solutions, and reduce our dependency on personal vehicles.

Fully autonomous vehicles are not yet available — technology is advancing, but challenges remain

There is considerable uncertainty regarding the level of deployment of CASE vehicles over the next decade. Assuming a resolution of near-term technological challenges and appropriate policy and regulatory development, autonomous shuttle and robo-taxi services could become available to Canadian consumers under limited scenarios, such as in urban cores, at international airports, or on campuses. However, the technological challenges are significant, and include limitations on batteries, sensors, data management and security, and AI, particularly with respect to operating in inclement weather, at night, and outside of a prescribed route or geo-fenced location. Regardless of the degree of sophistication of technology, social acceptability is uncertain — the use of a robo-taxi or autonomous shuttle will be a novel experience for most people in Canada. The majority of vehicles on the road in the next decade will continue to be conventional, but with incrementally higher levels of DAS, electrification, and connectivity.

CASE vehicles generate unprecedented volumes and new types of data that create risks to personal privacy and vehicle cybersecurity

Greater volumes and new types of data generated by CASE vehicles present an opportunity for increased safety, mobility coordination and efficiency, and improved accessibility. These data also open numerous business opportunities for automakers, mobility service providers, auto insurers, and others in the private sector. However, the risks to privacy also increase, not only from malicious actors or individual instances of abuse, but also from the gradual accumulation of seemingly minor practices for data collection and use by a variety of actors. Several types of organizations may have access to different types of data generated and collected by CASE vehicles, with competing claims of ownership to the same data, and no clear way to resolve these disputes. Data collected or generated in Canada may be transmitted and stored outside of Canada, and accessed or used by foreign companies and governments. This creates legislative and regulatory challenges around cross-border privacy and data protection. Technological capabilities to collect and analyze personal information are currently outpacing attempts to develop privacy standards or regulation related to informed consent and data collection in the context of CASE vehicles. Furthermore, there are significant cybersecurity considerations, challenges, and risks associated with CASE vehicles. Insufficient cybersecurity measures can cause unique safety risks, such as cyberattacks that take control of a vehicle's acceleration and steering, disable a vehicle or its sensors, or cause it to malfunction. Designing security protocols that are compatible across different vehicles and platforms and scalable across potentially millions of cars is a challenge.

The potential impacts of CASE vehicles are multifaceted and interconnected, which will require horizontal and coordinated actions

The interconnectedness of mobility systems touches all aspects of people's lives and all levels of government and the potential impact of CASE vehicles is profound. Part of the challenge of predicting the impacts of CASE vehicles on the Canadian economy, environment, and people is that many of these impacts will be determined by the collective decisions of many actors, whether they act in a coordinated, or uncoordinated and potentially antagonistic, manner. The regulation and investment decisions of municipal, provincial and territorial, and federal governments, in conjunction with companies, non-governmental organizations, and local communities, will determine the trajectory of CASE vehicle development. For example, the education system has a stake in predicting the skills and training necessary for successful employment in the future, which includes consideration of elementary and secondary school, as well as college and university programs and curricula. Supporting a productive workforce in Canada will also require planning and investment in support for workers whose jobs may be lost as production facilities themselves transition to greater automation. Moreover, the demand for training and skillsets will shift if driving jobs are lost and demand rises for fleet maintenance, inventory management, or other services. CASE vehicle deployment will also highlight issues with connectivity in rural areas and have impacts in such diverse areas as the arts, entertainment, and news media; road construction and maintenance; the electricity grid; aftermarket parts and services; fashion and wearable devices; and all kinds of seemingly obscure or unrelated aspects of people's daily lives. The impacts of CASE vehicle deployment are years away and depend on the development of technologies not yet realized, as well as a turnover in personal vehicle ownership that will likely take decades. It is challenging to draw clear boundaries around impacts when mobility informs decisions about when, where, how, and with whom we live, work, and play.

Summary

Fully realizing the promise of CASE vehicles to improve safety, reduce travel time, reduce emissions, and grow the economy depends on how industry, Canadians, and governments respond today to the potential challenges and opportunities. The issues facing CASE vehicle development and deployment are complex. Resolving them will require coordinated interactions and decision-making among relevant government authorities at all levels, as well as with relevant industry actors, associations, and international organizations. While the future of autonomous vehicle technology is uncertain, decisions made today will influence the adoption of CASE vehicles in the next 10 to 30 years.

Many of the challenges identified in this report are not necessarily unique to CASE vehicles. Addressing privacy and cybersecurity risks through better security of our connected devices and stronger privacy regulations will not only better prepare Canada for a CASE vehicle future, but also help mitigate these same risks in the many other network-dependent technologies that are used every day. Moreover, the economic, social, and environmental benefits of greater accessibility may be difficult to achieve without policy and regulation that support transportation equity and the integration of public transit and active transportation options with mobility services. CASE vehicles present both challenges and opportunities for Canadian industry, governments, and people in Canada, not individually, but in interconnected ways that will necessitate effective governance within and across government, industry, and the public.

Table 1 Areas of Opportunity and Challenge for the Development and Deployment of CASE Vehicles in Canada Over the Next 10 Years

Industry

Motor vehicle and parts manufacturing	ICT	Shared mobility
Transition to ICT R&D by manufacturers and parts suppliers	Incorporation of new companies and technologies into automotive supply networks	Growing markets and opportunities for expansion of services in urban areas
Production mandates for CASE vehicles and components essential for long-term relevance of Canadian manufacturers and suppliers	R&D and scale-up for new technologies (e.g., AI, operating systems, sensors)	New companies including automotive manufacturers entering the market
Education, training, and re-training of labour force to meet skills required for CASE vehicle production and servicing	New opportunity niches (e.g., infotainment, financial services)	Public-private partnerships (e.g., transit authorities, municipal governments, and private companies)
Transition to new opportunity niches (e.g., battery recycling, AI components) important for mitigating impacts related to the obsolescence of internal combustion engines and related parts manufacturers		

Government

Federal	Provincial and territorial	Municipal
Innovation policy and investment strategies to address Canada's role in the CASE vehicle economy	Innovation policy and investment strategies to address Canada's role in the CASE vehicle economy	Traffic, parking, and curbside access regulations to address the growing share of CASE vehicles
Trade agreements to clarify relationships for international companies and investors	Support and transition strategies for regional economies vulnerable to changes in the automotive sector	Infrastructure planning, upgrading, and maintenance to support the safe operation of CASE vehicles
Vehicle safety guidelines and standards for new technologies	Insurance regulations, traffic laws, and driver training and licensing changes to address increasing levels of automation	Transportation and mobility planning and regulation (i.e., integration of multiple services)
Harmonization of Canadian automotive and ICT regulations with the United States	Infrastructure planning, upgrading, and maintenance to support the safe operation of CASE vehicles	Urban planning and zoning decisions (e.g., urban density, access to public transit)
Communications infrastructure investments, standards, and regulation (including data privacy)	Education and training to ensure a skilled workforce in the CASE vehicle sector as well as in new opportunity niches	Public-private partnerships and new revenue streams (e.g., congestion pricing)
Environmental pollution and air quality standards in light of new technologies	Environmental pollution and air quality standards in light of new technologies	Mobility-as-a-Service (MaaS) opportunities (i.e., the integration of multiple offerings)
Infrastructure investment to support equitable access across communities (e.g., rural connectivity)		

Abbreviations

ADAS	advanced driver assistance system
ADS	automated driving system
AI	artificial intelligence
CASE	connected, autonomous, shared, and electric (vehicle)
CAV	connected and autonomous vehicle
DAS	driving automation system
DSRC	dedicated short-range communications
EV	electric vehicle
ICE	internal combustion engine
ICT	information and communications technology
LIDAR	light detection and ranging
MaaS	Mobility-as-a-Service
NHTSA	National Highway Traffic Safety Administration (United States)
OEM	original equipment manufacturer (automaker)
V2__	vehicle-to communications, can be: V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure), V2X (vehicle-to-everything)
VKT	vehicle kilometres travelled

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Introduction

Connected and autonomous vehicles (CAVs) hold the promise of a transportation revolution and are poised to deliver a wide range of social and economic benefits. For example, some experts predict that autonomous vehicles could substantially reduce fatalities from collisions in Canada (Godsmark *et al*., 2015). CAVs offer the potential for a more effective, efficient, and integrated transportation system, with reduced congestion, fewer collisions, and greater mobility options. CAVs could lead to improved equity and accessibility in transportation for older adults, children and youth, people with limited mobility, and those living in underserved areas. These vehicles present new business opportunities for industry, including software development, shared mobility services, infotainment, and infrastructure. The global market for CAVs is projected to grow by over 18% between 2020 and 2025 (Research and Markets, 2020). Canada is well positioned to take advantage of this expansion with strengths in automotive manufacturing and information and communications technology (ICT).

> In this report, *autonomous* is used to describe an object (e.g., autonomous vehicles) and *automated* is used to describe a process or action (e.g., automated driving).

CAVs also present several challenges to realizing these benefits. For example, while their emergence is likely to spur increased demand for workers in ICT, other jobs, particularly those dependent on human drivers, will likely be phased out and eventually displaced. Indeed, CAVs will likely disrupt a wide range of industries, such as the auto sector (including original equipment manufacturers (OEMs), parts manufacturers, aftermarket suppliers, dealerships, and repair services); transportation services such as ride hailing and car sharing; trucking and delivery services; ICT; insurance; and banking and finance. Because of these challenges, new business models will be needed. Significant privacy and cybersecurity risks are associated with the vast amounts and new types of data generated and collected by connected vehicle technology companies. Manufacturing and safety standards will require harmonization with global trading partners, notably the United States. Canada's natural environment also creates technical challenges. Cold and snowy weather can pose problems for sensors as well as for battery life, and rural and remote communities already struggle with connectivity and infrastructure upgrades, both of which may be vital to supporting fully automated driving.

To prepare for the impacts, capitalize on the potential benefits, and overcome the challenges described above, governments at all levels will have a major role to play in developing policy and regulations for CAVs, as well as in supporting research and industry innovation. In 2020, Canada ranked 12th out of 30 countries in KPMG's

Autonomous Vehicles Readiness Index, which found the country to be lagging behind some comparable jurisdictions, particularly in infrastructure, technology and innovation, and consumer acceptance (KPMG, 2020a). In addition, the Senate Standing Committee on Transport and Communications (2018) report on CAVs concluded that "Canada is ill-prepared for the fast-approaching future of transportation."

The transition from human-driven, personally owned cars to connected, autonomous, shared, and electric (CASE) vehicles is a technological and mobility revolution that may significantly improve vehicle safety, transportation equity, environmental quality, and living standards. Conversely, these vehicles may exacerbate traffic congestion, increase transportation inequities, and lead to worse air quality. Realizing the benefits, and avoiding the downsides, will require support and guidance from governments, industry, and the Canadian public in order to achieve convenient, affordable, healthy, and safe transportation for all.

1.1 Charge and Scope

In recognition of the transformative potential of new transportation technologies and trends, Innovation, Science and Economic Development Canada asked the Council of Canadian Academies (CCA) to convene an expert panel to provide an evidence-based, authoritative assessment on the opportunities, challenges, and impacts of CAVs and shared mobility in Canada. Specifically, the CCA was asked to answer the following question and sub-questions:

In light of the current trends affecting the evolution of connected and automated vehicle technologies and shared mobility, what impacts, opportunities and challenges do these present for Canadian industry, governments and Canadians more broadly?

- What economic, social and environmental implications will these technological trends have on Canadians?
- What economic, social and environmental implications will these technological trends have on Canadian industry, including automotive as well as other industries that could be affected by technology trends and changing business models? Include opportunities for the Canadian industry.
- What economic, social and environmental implications will these technological trends have on government policy and regulations in Canada?

To address the charge, the CCA assembled a multidisciplinary panel of 12 experts (the Panel) with a balance of academic and industry perspectives from across Canada. To address the wide range of potential impacts of CAVs, Panel members brought knowledge from the disciplines of computer, electrical, civil, and mechanical engineering; environmental science; kinesiology; political science; geography; ethics; and the automotive, ICT, and shared mobility industries. Each member served on the Panel as an informed individual rather than as a representative of a specific discipline, organization, region, or set of values. The Panel met in person and via videoconference five times from June 2019 to July 2020.

The Panel focused its discussions on the impacts of CAVs by working under the assumption that technology is moving towards a future in which vehicles will not only be connected and autonomous, but also shared and electric (i.e., CASE vehicles). For example, the impacts of the first (and presumably expensive) autonomous vehicles on Canadians will vary dramatically depending on whether they are available only for private purchase, in car-sharing operations, or as part of commercial fleets offering ride-hailing services. Similarly, the impacts on industry will depend on whether automakers shift business models away from the manufacturing and selling of a product to the provisioning of mobility services. Therefore, given the high cost of new technology, the stated interest of ride-hailing companies in autonomous vehicles, the movement towards vehicle electrification, and the growing shared mobility service sector, the Panel assumed that CAVs will also be shared and electric. While this assumption underpins the discussion of potential impacts (e.g., Figure 1.1), it does not represent the Panel's prediction about the actual future use of these technologies. The Panel notes that there is considerable uncertainty associated with this assumption, identified in the text where appropriate.

Figure 1.1 Key Beneficial Impacts to People in Canada from CASE Vehicles

Connected, autonomous, shared, and electric (CASE) vehicles can lead to benefits for people in Canada, including improved safety, more efficient and affordable mobility, cleaner air, and reduced congestion. However, these benefits depend on the combination of attributes from all four characteristics, as well as public policy decisions at all levels of government.

At the outset of the assessment process, the Panel met with the Sponsor to acquire a full understanding of the charge and receive additional direction on its scope. This report does not consider aerial vehicles (i.e., drones), nor does it examine in depth autonomous public transit vehicles (i.e., buses and trains). Rather, it provides an objective assessment of the current evidence on the social, economic, and environmental impacts of CASE vehicles in Canada, which includes impacts on transit use and modes of transportation, industry and business models, privacy and cybersecurity, and health and equity. To establish boundaries for the discussion on impacts, CASE vehicle-related sectors such as oil extraction and distribution, air travel and hotels, and retail services were out of scope.

Note that this report uses CASE vehicle as an umbrella term wherever possible, though the references cited may be specific to one or more of the component characteristics (e.g., CAVs or shared autonomous vehicles). Note that CAVs is used in circumstances where CASE would be inappropriate.

Well into the Panel's deliberations, the world experienced the widespread emergence of COVID-19, raising critical questions about the potential impacts of the pandemic on the assumptions and findings of the report. While the Panel recognized that the pandemic will undoubtedly have significant consequences on CASE vehicles, they also felt that there is little reliable evidence to justify including the consequences of the pandemic in this report at the time of publication. However, the Panel agreed that the gravity and breadth of the consequences will likely be significant, and have included a review of early discussions on the topic at the end of this report (Afterword).

1.2 Approach and Evidence

In assessing impacts of CASE vehicles in Canada, the Panel recognized the inherent uncertainty associated with projecting into the future, especially given the pace of technological change. To minimize this uncertainty, the Panel adopted a 10-year outlook with the understanding that such a timeframe aligns well with the Sponsor's priorities for policy planning and decision-making. Many of the major impacts from CASE vehicles, however, are much further out. Changes to travel behaviour, car ownership, transportation systems, urban geography, and social dynamics may not occur until autonomous vehicles diffuse widely (i.e., outside of geographically limited core areas); this may well be over 30 years away.

Within the next 10 years, however, governments will face decisions on the anticipation and early appearance of CASE vehicles on Canadian roads. To this end, the Panel examined impacts in policy areas critical to CASE vehicle development and diffusion: industry, including the automotive sector, ICT, and insurance; data, privacy and cybersecurity; mobility and urban planning; the environment; and the safety and well-being of people in Canada.

In identifying relevant evidence, the Panel focused mainly on conditional to fully autonomous vehicles (Society of Automotive Engineers (SAE) Levels 3–5; see Table 2.1). Five types of evidence were considered:

- literature from peer-reviewed publications, reports, publicly available government documents, and grey literature;[1]
- quantitative and qualitative data drawn from a variety of sources, including Statistics Canada, Transport Canada, and comparable organizations in other jurisdictions;
- primary research in the form of semi-structured interviews with experts from industry and stakeholder groups to obtain further insights, in addition to those available in published literature and data;
- press releases and media for the latest information on new and emerging vehicle technologies; and
- the expertise of Panel members and insights from Panel deliberations.

Uncertainty about technology and other key trends in the development and deployment of CASE vehicles in Canada make predicting impacts difficult. Furthermore, evaluating the relative quality or credibility of predicted or projected impacts can be challenging given the breadth of disciplines, sectors, and stakeholders from which this assessment draws its evidence. The Panel sought only those documents and studies that were of sufficient quality as determined by some or all of the following criteria:

- **Peer review:** Preference is for publications that have gone through peer review. However, not all sectors examined use peer review (e.g., industry reports), therefore, it is not a requirement for inclusion as evidence.
- **Transparency:** Are the authors clear and thorough in their description of the methodology or rationale? Do they state their assumptions? Are there conflicts of interest? Do the authors report the level of uncertainty associated with their predictions?

1 *Grey literature* refers to various types of documents, produced by government, academics, industry, and other organizations, that are not published commercially or formally.

- **Representation:** Sample size and breadth are considered when evaluating the quality of inferences drawn from a study.
- **Source and methodology:** Are predictions based on a single source, or were multiple sources (interviews, surveys, scenarios, etc.) considered? Are the methods used standard practice in the discipline? If not, is the rationale for the methodology clear and reasonable?
- **Expertise:** How familiar, experienced, or well regarded are the individuals expressing their opinions or predictions about the future? What specific expertise do they represent?
- **Concordance:** Do multiple credible sources support a particular prediction or opinion?

1.3 Report Outline

The appearance of CASE vehicles on public roads in Canada is inevitable, despite uncertainty about the timing. In some ways, it is already happening today **(Chapter 2)**. The report focuses on key areas of impact for Canadian industry, government, and the public: CASE Vehicles and Industry **(Chapter 3)**; Insurance and Liability **(Chapter 4)**; Data, Privacy, and Cybersecurity **(Chapter 5)**; Mobility Planning **(Chapter 6)**; and Health and Well-Being **(Chapter 7)**. **Chapter 8** summarizes the Panel's response to the assessment questions and offers reflections on the future of mobility in Canada.

2

Examining the Case for CASE Vehicles

Connectivity, automated driving, shared mobility, and electrification are trends in vehicle technology and use that are developing in parallel. While each could develop in isolation (e.g., an autonomous vehicle does not require an electric powertrain, nor does shared mobility demand vehicle automation), in practice, these trends are often intertwined (e.g., automotive manufacturers are developing autonomous vehicles that are also connected and electric). To facilitate their deliberations, the Expert Panel worked under the assumption that CAVs will also be shared and electric.

Panel Assumptions: Why CASE and not CAVs?

Autonomous vehicles will also be connected vehicles. Though they will need to be able to function safely if connectivity is lost, autonomous vehicles operate most effectively when in communication with their environment, including other vehicles, pedestrians, and infrastructure. Moreover, some connectivity will be necessary for updating software, navigation data, and other services.

Connected and autonomous vehicles will initially be shared. The business model of personally owned vehicles may not be suited to CAVs, as the initial cost of these vehicles will likely be prohibitive to a majority of consumers. However, organizations operating shared mobility services may be better positioned to assume the initial cost of purchasing CAVs, given the projected operational cost savings.

Connected, autonomous, and shared vehicles will also be electric. The electrification of the vehicle fleet is a current trend that will continue in the face of growing political, societal, and environmental pressures to reduce reliance on fossil fuels.

In the next 10 years, CASE vehicles will be on roads in Canada under limited geographic and operational conditions. More vehicles will have advanced driver-assistance systems and hybrid or electric powertrains. New mobility service options will likely include low-speed driverless shuttles and robo-taxis in dense urban areas or on private property (e.g., core service areas, airports, and campuses).

CASE vehicles are expected to be a disruptive transportation technology that will benefit society, changing travel behaviour and transportation network performance (Fagnant & Kocklman, 2015; Burns & Shulgan, 2018; Herrmann *et al.*, 2018). Since many of the challenges, opportunities, and implications of CASE vehicles (e.g., changes in driving jobs, congestion, and vehicular fatalities) depend on their wide-scale adoption, credible estimates of the timing and scale of CASE vehicle market diffusion are needed to design and implement policy and regulation.

Predicting the roll-out of CASE vehicles on Canadian roads requires parsing out when technical limitations (e.g., battery life, artificial intelligence (AI), and network capacity) and societal constraints (e.g., acceptability, trust, and affordability) will be overcome. This is complicated by the potential for rapid change or slowed growth from unanticipated political, economic, or societal turns. A large-scale failure of, or cybersecurity attack on, CASE vehicles that causes injuries and fatalities could put the brakes on further deployment and societal acceptance of this technology. Rather than focusing on specific timelines, this chapter lays out the Panel's observations on current pilot projects and commercial operations addressing each of the characteristics of CASE vehicles and their potential impacts in the next 10 years.

2.1 Connected Vehicles

Connected vehicles have been on the road for over 20 years. General Motors (GM) first introduced its OnStar system in 1996, which used satellite communications technology to open a car's power lock doors remotely in the event a driver was locked out (Fleming, 2015). Subsequent iterations and developments by numerous automakers allowed vehicles to use satellite technology to communicate the location of a collision and provide navigation information (Fleming, 2015). Smartphone-based vehicle telematics have been tested and used around the world for over a decade, with applications in insurance, as well as traffic monitoring and management (Wahlström *et al.*, 2017); the first use of telematics by an auto insurance company in Canada was in 2013 (IBC, 2017). In 2014, the first vehicles with built-in, fourth-generation, long-term evolution (4G-LTE) connectivity were available for purchase worldwide, which allowed the vehicle itself to create a Wi-Fi hotspot for other devices to connect to the internet (Fleming, 2015). Connectivity in personal vehicles was typically available only as a premium feature in high-end models until recently (Gogolek, 2019). However, connected vehicles are now common and are becoming ubiquitous.

2.1.1 Connectivity in the Next 10 Years

Connectivity in existing consumer vehicles is used for infotainment (i.e., information and entertainment services), communications, navigation, remote diagnostics, and alerting emergency services (Lawson *et al.*, 2015). Typically, these services are delivered via the existing cellular network and many connect to a driver's smartphone. In the future, however, automated driving systems are likely to use vehicle-to-everything (V2X) communications to transmit and receive information to and from other vehicles, roadside infrastructure, pedestrians, cyclists, and even the electrical grid (Box 2.1).

Box 2.1 Types of V2X Communications

Vehicle-to-Everything (V2X) is a catchall term that covers a range of different connected vehicle applications, including:

Vehicle-to-Vehicle (V2V): Communication with other vehicles to provide complementary and redundant sensor information, and to coordinate vehicle behaviour.

Vehicle-to-Infrastructure (V2I): Communication with roadside infrastructure (e.g., traffic signals, road signs, intersections, pedestrian crossings). V2I will require the installation and deployment of a very large number of network access points known as roadside units.

Vehicle-to-Network (V2N): Communication with wireless networks to share traffic information, call emergency services, and provide infotainment. V2N relies on cellular network infrastructure.

Vehicle-to-Pedestrian (V2P): Communication with pedestrians for the purpose of detection and proximity warnings, as well as requesting a shared vehicle. V2P will require connections to a pedestrian's mobile phone or other wearable device(s).

Vehicle-to-Grid (V2G): Communication with the power grid for the purposes of recharging an electric vehicle.

Keysight (2018), McQuinn and Castro (2018), Steadman and Huntsman (2018)

Connectivity facilitates automated driving by providing a way for vehicles to (i) verify the accuracy of information from onboard sensors by comparing to an external source, and (ii) extend the reach of the vehicle's perceptual abilities by providing data about the world beyond the range of its own sensors (SSCTC, 2017c). Furthermore, connected vehicle technology (CVT) could enable vehicles to transmit information about their position and velocity, planned movements, and the location of objects in their immediate environment to any other connected vehicle. This may be done directly (using V2V, if they are nearby) or indirectly via infrastructure (V2I) or a wireless network (V2N). CVT could thus allow vehicles to coordinate movement for more efficient traffic flows and to help avoid collisions (McQuinn & Castro, 2018; Shladover, 2018; Narayanan *et al.*, 2020). Moreover, in cases of sensor failures, data from another vehicle's sensors could be used to safely guide the vehicle (a type of safety redundancy called *sensor virtualization* (Anderson *et al.*, 2016)). Indeed, CVT could also allow for the design of vehicles in which the task of driving is distributed among infrastructure and vehicles (SSCTC, 2017c), and potentially even cloud-based servers.

Connected vehicles will use DSRC, 5G, or both

The two main communication technologies for future connected vehicles are dedicated short-range communications (DSRC) and fifth generation (5G) networks (McQuinn & Castro, 2018; SSCTC, 2018). There is debate over which technology is better suited for CASE vehicles. Some experts suggest that one likely outcome is a mix of the two, as DSRC works better at short distances, whereas 5G is more useful for wide-range coverage (SSCTC, 2018; Elliott *et al.*, 2019). Connected vehicles today use other communications technologies such as Bluetooth, 4G-LTE, and Wi-Fi (Anderson *et al.*, 2016; McQuinn & Castro, 2018).

The uncertainty over which technology will become the dominant vehicular communication technology may be hindering development of CASE vehicles (Steadman & Huntsman, 2018). Both 5G and DSRC can offer direct device-to-device connectivity, which means they can likely provide the same basic safety applications (Steadman & Huntsman, 2018; Elliott *et al.*, 2019). Unlike 5G, DSRC cannot support non-safety applications, such as traffic information and infotainment, without the deployment of additional roadside infrastructure (Shah et al., 2018). However, DSRC is reliable in all but the most extreme weather conditions (Schoettle, 2017), whereas 5G is hindered by rain and foliage (Nordrum & Clark, 2017). Adding to the uncertainty is the fact that 5G is not expected to become available until the early to mid-2020s (Accenture Strategy, 2018; Collins *et al.*, 2018; Davidson & McLaughlin, 2018) Some automakers are nonetheless betting that 5G will be the primary technology for V2V and V2I communications (GSMA, 2019), while others are embracing DSRC (Steadman & Huntsman, 2018).

2.1.2 Connectivity and Automated Driving

Currently, connectivity is essential for the safe operation of autonomous vehicles, if only to maintain up-to-date software and navigation data. However, whether V2X technology is needed for future autonomous vehicles is unclear. V2X communications may be necessary to maximize the potential of automated driving systems (e.g., Gowling WLG & UK Autodrive, 2018). Some experts claim that, given the vast geography and diffuse population of Canada, it is simply not possible for a vehicle to be connected to a network everywhere at all times; Canada may therefore require autonomous vehicles that can function safely without being constantly connected (SSCTC, 2017b). Regardless of the requirement for absolute connectivity, there is little doubt that future vehicles will use connectivity for purposes not directly involved in the task of automated driving, such as: updating internal maps; offering information on traffic, road, and weather conditions; and providing remote diagnostic services and software updates to vehicle computer systems. Additionally, CVT will likely expand infotainment, such as streaming audio and video, internet browsing, news, and communications, including phone, email, text, and social media (e.g., Holmes & Alantz, 2019). CVT is also vital to shared mobility service providers for managing fleets of vehicles, and in other shared vehicle applications (Section 2.3).

2.2 Autonomous Vehicles

The most commonly used standard for classifying the level of automation in a vehicle comes from the Society of Automotive Engineers (SAE) (Table 2.1). Driving automation systems that are available today span Level 0 through 2 and include basic active safety systems such as anti-lock brakes and electronic stability control, as well as Advanced Driver Assistance Systems (ADAS). The British Standards Institution (2020) defines ADAS as an "entity consisting of interdependent components that supports human drivers by performing a part of the dynamic driving task or providing safety-relevant information." ADAS can include functions related to driver control assistance (e.g., adaptive cruise control, lane-keeping assistance), collision warnings, collision intervention (e.g., automatic emergency braking), parking assistance, and other driver assistance systems (e.g., automatic high beams) (Consumer Reports, 2019). Notably, having a vehicle with ADAS could mean anything from having a backup camera to Tesla's Autopilot system; however, regardless of the technology available, all ADAS function to assist, not replace, an engaged driver (Consumer Reports, 2019).

Some of these systems have been available in vehicles long enough to demonstrate that they increase road safety, as identified in *Canada's Road Safety Strategy 2025* (2016). These include:

- **Automatic emergency braking systems:** Technology that applies the brakes when it detects objects in front of a vehicle and combines that detection with information on vehicle speed and trajectory (e.g., Cicchino, 2016).
- **Electronic stability control:** Detects when the vehicle starts to lose control and uses selective braking and reduced engine power to attempt to maintain the intended direction of travel (e.g., Chouinard & Lécuyer, 2011).

- **Rear view and braking technologies:** Rear view cameras help drivers avoid collisions when objects are behind the vehicle, particularly for large SUVs, which tend to have the worst rear visibility (IIHS, 2014). Coupling cameras and sensors with automatic braking technology is likely to be more effective than sensors and cameras alone, as has been demonstrated with front crash warning systems (IIHS, 2014).

Table 2.1 SAE Levels of Automation

SAE Level	Description
Human performs part or all of the dynamic driving task (i.e., human must always be able to take over driving)	
Level 0 **No automation**	A human controls all aspects of driving. However, performance may be enhanced by active safety systems.
Level 1 **Driver assistance**	A driving automation system (DAS) assists a human driver by controlling **either** steering **or** braking and accelerating, but not both at the same time. The DAS is engaged and disengaged only at the driver's request. The human driver must still pay full attention and perform the remainder of the dynamic driving task.
Level 2 **Partial driving automation**	A DAS controls both steering **and** braking and accelerating at the same time, under some circumstances, while the human driver performs the rest of the driving task. The DAS is engaged and disengaged only at the driver's request. The human driver must still pay full attention and perform the remainder of the dynamic driving task.
Automated Driving System performs the dynamic driving task while engaged	
Level 3 **Conditional driving automation**	A type of DAS called an automated driving system (ADS) performs the dynamic driving task in a sustained manner under specific operating conditions (e.g., on certain roads or types of roads), with the expectation that the human driver is available and ready to intervene at the request of the ADS or in the event of failures in other vehicle systems (i.e., the human must be ready as a fallback).
Level 4 **High driving automation**	An ADS performs the dynamic driving task in a sustained manner under specific operating conditions (e.g., on certain roads or types of roads, or in specific geographic locations). Under those conditions, the human driver does not need to pay attention, nor do they need to be ready to take over if necessary — they become a passenger when the system is engaged.
Level 5 **Full driving automation**	The sustained and unconditional performance of an ADS for the entire dynamic driving task; humans are passengers with no expectation they will need to intervene in the driving task.

Adapted from SAE (2018)

ADAS available today (e.g., adaptive cruise control, lane keeping, blind spot alerts) will continue to diffuse in the Canadian vehicle market, depending on costs (price, maintenance, and repairs) and consumer demand for these technologies, as well as government regulations on safety standards for new vehicles, and training and licensing requirements for drivers.

2.2.1 Automation in the Next 10 Years

There are numerous concerns over the deployment of SAE Level 3 personal vehicles, which are capable of automated driving, but always require a human driver to remain vigilant and able to take control over the vehicle. Drivers must understand and comply with their responsibilities in each driving mode, particularly in the moments when driving modes change (i.e., when a user is expected to take over) (Wood *et al.*, 2019). This requirement is particularly problematic after long stretches of automated driving, where the user's attention can wander, even to the point of falling asleep (e.g., Haskins, 2019). Moreover, the design of the switchover, that is the specific "pay attention now" request and the time required for the user to take over, has yet to be optimized (Inagaki & Sheridan, 2019). Audi's Level 3 "Traffic Jam Pilot" for 2019 A8 vehicles, which was only made available for vehicles purchased in Germany, was ultimately blocked from being enabled in those vehicles because of a lack of clarity regarding their legality on German roads (Bishop, 2019). Whether other automakers will debut commercially available Level 3 vehicles in the coming years, and whether regulations will allow this technology on public roads, remains to be seen (Bishop, 2019).

Autonomous vehicles are being used in industrial operations and in commercial trucking

Autonomous vehicles are being used today in mining operations (Shpieva, 2019) and in agriculture (Robinson *et al.*, 2019); such vehicles are also being tested in military applications (O'Dell, 2019) and for freight deliveries in the United States (Hirsch, 2019). Suncor Energy announced the use of autonomous hauling systems in an oil sands mine in Canada, with plans to bring 150 such vehicles into operation by 2025 (Oil Sands Magazine, 2019).

A U.S. Department of Transportation review of safety regulations for automation in commercial vehicles considered ADAS in combination with V2V communications and sensors (e.g., platooning) as the most plausible application of automation in commercial motor vehicles (Perlman *et al.*, 2018). Platoons can be defined as groups of individual motor vehicles travelling together in a unified manner through electronic coordination (e.g., V2V communication) at speeds and distances faster and closer than would be reasonable without such coordination (Scribner, 2018). Studied since the 1990s, truck platooning has demonstrated benefits for fuel efficiency and GHG emission reduction (Mendes *et al.*, 2017). Platooning has been tested on closed courses and public roads in jurisdictions including the United States, Europe, and Japan (Blanco, 2019). In Canada, logging trucks in Quebec (Roy, 2019) and transport trucks at Transport Canada's testing facility in Blainville, Quebec, have tested platooning (TC, 2019j). While the trucking industry is pursuing platooning to reduce emissions and improve safety, some critics question its commercial viability. Newer trucks are increasingly aerodynamic and maintaining a platoon for long distances (as trucks make deliveries to different destinations) poses logistical challenges (Saracco, 2019). Some companies have moved away from investing in platooning R&D to ADAS development and improved aerodynamic features on their vehicles (Adler, 2019). Specific challenges to the widespread use of platooning include cooperation among fleet management companies to ensure fairness, interoperability, and logistical coordination (Adler, 2019).

Autonomous low-speed shuttles and public transit vehicles are in an early phase

Vehicles with fully automated driving capabilities under restricted route conditions are typically conceived as shared mobility solutions that operate on a fixed route with shared right-of-way (Cregger *et al.*, 2018). They carry between 4 and 15 passengers, though some companies are exploring smaller pods for one or two people (Cregger *et al.*, 2018). The Pacific Western Group of Companies has been running an electric autonomous shuttle, which can carry up to 12 passengers at a time, in pilot projects across western Canada since September 2018 (ELA, 2018). In Montréal, Transdev Canada launched a pilot autonomous shuttle service (Easy Mile) in June 2019 that navigated a 1.4 km route through normal traffic in a dense urban environment (Transdev Canada, 2019). Keolis Canada's demonstration project ran a fully electric, autonomous shuttle built by Navya along a 2.0 km route in the city of Candiac, near Montréal, from October 4, 2018 to December 31, 2019 (Keolis Candiac, n.d.).

In a review of the state of the practice, Cregger *et al.* (2018) consider these vehicles as largely prototypes, since frequent software and hardware updates are still needed, and appropriate use cases and evaluation metrics for performance are still unclear. Many low-speed shuttle manufacturers are new to vehicle manufacturing and production is not yet at scale, though pilot projects do show promise in solving the "first/last mile" problem[2] (Cregger *et al.*, 2018). The commercial deployment of such shuttle services appears highly likely, particularly in localized areas such as airports, public transit routes, hospitals, assisted living communities, and educational or industrial campuses. For

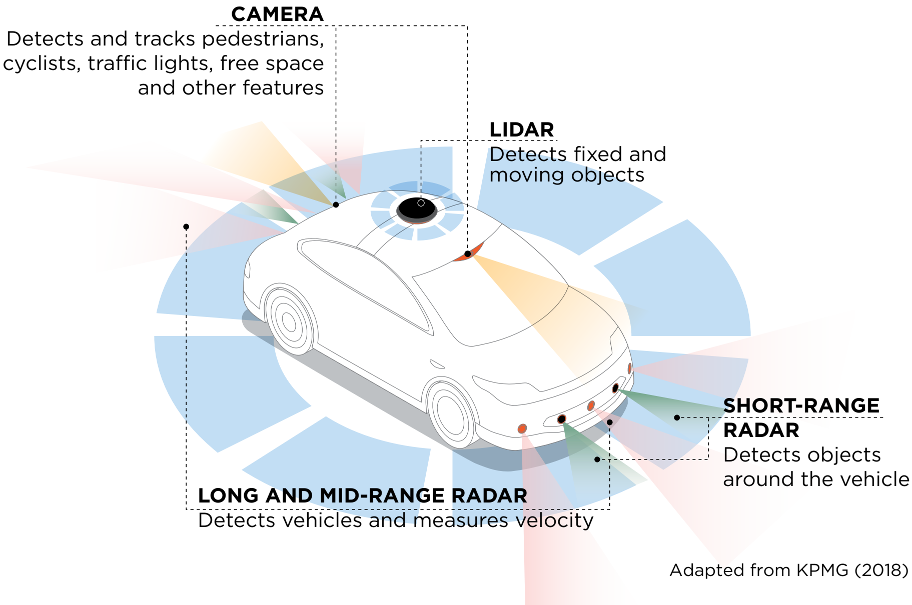
2 That is, the mobility challenge of transportation to and from a destination and the nearest access point for public transit.

example, the commercial operation of low-speed autonomous shuttles on the private roads of an industrial park in New York opened for business in August 2019 (Hawkins, 2019b). In Europe, the business park Rivium ParkShuttle began operation of an autonomous shuttle service between two stations approximately 1.2 km apart on a single-lane road in 1999 (2getthere, 2018). In 2005, the system was expanded to include larger vehicles and a longer route (1.8 km), servicing five stations and intersecting with car and pedestrian traffic (2getthere, 2018).

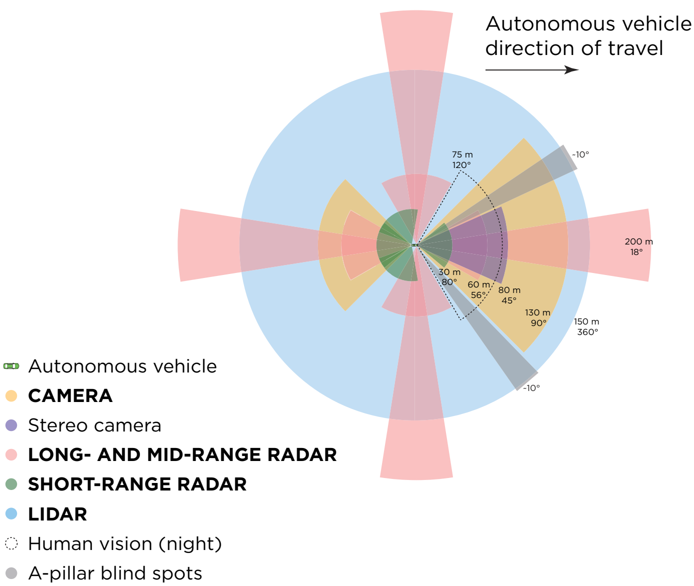
Automated driving is also of significant interest to transit operators. China unveiled an autonomous intercity bus service in 2015 (Metcalfe, 2015). New Flyer, the largest bus manufacturer in North America, headquartered in Winnipeg, Manitoba, announced a new autonomous technology program in May 2019 (New Flyer, 2019). Abe (2019) estimates that operating costs for buses could decrease by 53% in a fully autonomous bus system in Japan, largely because of the reduction in salary expenditures. A systematic review of the literature on fully autonomous buses found operating costs could be reduced by upwards of 50 to 60% (Azad *et al.*, 2019). In regional metropolitan and rural areas, Japanese bus operators have an average operating deficit of 13% (Abe, 2019); in comparison, Ontario transit operators reported an operating deficit of approximately 40% in 2015 (CUTA, 2016). Transit services are heavily subsidized in Canada (e.g., CUTA, 2016), and decreasing operating costs through automation could prove attractive for many municipalities, though the Panel notes that up-front costs for new buses, coupled with current operating deficits and the potential for job losses among transit operators, may slow or limit the uptake among transit authorities. However, cost savings from automation may exceed capital costs of new vehicles for some transit authorities, and automation itself allows for smaller transit vehicles that can address a broader spectrum of service demands (Tirachini & Antoniou, 2020).

2.2.2 State of Autonomous Vehicle Technologies: Sensors and AI

Autonomous vehicles rely on several different types of onboard sensors — mainly cameras, light detection and ranging (LIDAR), and radar — to provide the information needed to navigate their environment (Figure 2.1). Other types of sensor technologies (such as ultrasonic) may play a supporting role. Many sensor-based systems are already in use in vehicles for safety applications such as collision warnings, emergency braking systems, parking and lane-keeping assist systems, and backup cameras (CCMTA, 2016). Each type of sensor has advantages and disadvantages, and performs different tasks (Table 2.2). Cameras, LIDAR, and radar are all used for object detection; LIDAR produces detailed 3D maps ("point clouds") of the vehicle's surrounding environment (Kocić *et al.*, 2018), cameras



Adapted from KPMG (2018)



Source: Schoettle (2017)

Figure 2.1 Autonomous Vehicle Sensors

Type and placement of sensors for autonomous vehicles (top) and their detection ranges (bottom).

identify and classify objects, and identify roadway and environmental conditions (Schoettle, 2017), and radar accurately detects the speed and direction of movement of objects in the vehicle's environment (Davies, 2018). Cameras and LIDAR are unable to "see" in conditions of poor visibility or bad weather (e.g., snow, fog); radar is largely immune to such conditions, although it has difficulty detecting non-metallic objects (Anderson *et al.*, 2016; Schoettle, 2017; Kutila *et al.*, 2018). Because different types of sensors provide different types of information and have different limitations with respect to their abilities, range, operating conditions, and types of objects they can sense, vehicles are equipped with a variety of sensor types to make up for the limitations of any one type, to provide redundancy and to increase safety (Anderson *et al.*, 2016; Schwarting *et al.*, 2018).

Autonomous vehicle technology must work in all environmental conditions, be able to combine data from multiple sources seamlessly, as well as locate and position the vehicle at all times

Weather conditions such as dense precipitation and fog can pose problems for multiple sensors simultaneously (i.e., both cameras and LIDAR), thereby limiting the utility of multiple-sensor suites (Anderson *et al.*, 2016; Schoettle, 2017). Physical obstructions on a vehicle, such as snow and ice, can hinder all types of sensors (Schoettle, 2017); this is a challenge that researchers in Canada are working on (e.g., UofT News, 2020). Notably, the difficulties that winter weather conditions pose for sensors have helped to attract researchers and developers to conduct autonomous vehicle testing in Canada (Lampert, 2018). Sensors may also have trouble navigating construction and roadwork, as they may be unable to recognize features or signs indicating abrupt changes in road conditions, or understand complex or poorly marked detours (Anderson *et al.*, 2016).

To navigate safely at a level comparable to that of human drivers, autonomous vehicles must integrate data from different types of sensors into a unified representation of the roadway and surrounding environment — this is called sensor fusion (Schoettle, 2017; Kocić *et al.*, 2018). As noted in Table 2.2, each sensor type has both strengths and weaknesses in providing accurate and precise perception of the environment. Cameras provide highly detailed 2D information about, for example, colour intensity, density, and edge information, which is then mapped onto 3D point cloud data provided by LIDAR (Kocić *et al.*, 2018). While computationally intensive, sensor fusion is necessary to reduce uncertainty from any one sensor's measurement, improving the fault tolerance of the vehicle's perception system (Rosique *et al.*, 2019).

Autonomous vehicles typically use a combination of the Global Positioning System (GPS) and the Inertial Navigation System for determining their geographical position. However, over a 10-second period during which a vehicle is relying solely on Inertial Navigation System (because a GPS signal is unavailable), "drift" can create errors of more than a metre (Anderson *et al.*, 2016). Simultaneous localization and mapping (SLAM) can compensate for drift errors by constructing a map using information from the vehicle's sensors while simultaneously locating itself within the map (Woo *et al.*, 2019). Fusion methods are being developed to improve positioning precision using combinations of positioning systems and perception sensors (Rosique *et al.*, 2019). Specialized high-definition (HD) maps contain detailed, real-time information about objects and features in a vehicle's environment, including other vehicles, traffic and road conditions, roadside infrastructure, traffic signals and signs, speed limits, roadside barriers and obstacles, road and lane boundaries, parking spaces, off-ramps, and more (Kent, 2015; Vardhan, 2017; Chellapilla, 2018). In a sense, HD maps act as a canvas on which all data about the external environment are represented (Kent, 2015).

Table 2.2 Sensor Types Used in Combination for Automated Driving

	Camera	LIDAR	Radar
Strengths	• Identification of objects and features in the surrounding environment (appearance and resolution) • Can detect colour	• 360-degree, 3D point clouds of surrounding environment • Highly detailed information about distance, size, and shape of objects (identification) • Very high spatial resolution	• Detects speed and direction of objects • Long-range detection • Provides highly accurate distance information
Weaknesses	• Requires computationally intensive image processing ("semantic segmentation") • Detecting size of objects	• Not very accurate in measuring an object's speed • Difficulty detecting objects at close distances • Less useful with materials that do not reflect a lot of light • Computationally intensive	• Does not work well on non-metallic objects; may not detect pedestrians • Low resolution
Environmental considerations	• Ineffective in darkness and low illumination • Limited by snow, fog, rain, and dusty conditions	• Works in all lighting conditions • Effectiveness is limited by snow, fog, rain, and dusty conditions	• Works well in all or most weather conditions • Works well in darkness or low illumination
State of development	• Mature technology • Image processing requires further development of machine learning	• Developing technology • Currently attempting to reduce size and costs	• Mature technology • Currently undergoing shift in operating frequencies

Varghese and Boone (2015), Anderson *et al.* (2016), Rudolph and Voelzke (2017); Schoettle (2017), Davies (2018), Khader and Cherian (2018), Kocić *et al.* (2018), Neal (2018), Rosique *et al.* (2019)

Advancements in AI are needed before autonomous vehicles are able to operate at a level comparable to human drivers

Analyzing and interpreting the raw data that sensors collect about a vehicle's external environment and then driving accordingly — i.e., AI — is a difficult challenge in the development of fully autonomous vehicles. While the low-speed shuttles, industrial vehicles, and even the robo-taxis as described above are likely to become more common in limited circumstances in the next 10 years, the technical challenges described below add considerable uncertainty as to when fully autonomous personal vehicles will be available anywhere in Canada.

To operate at a level comparable to human drivers, autonomous vehicles require AI to "perceive," "think," and "reason" (Ma *et al.*, 2020). Advances in perception and control algorithms are continuing, but humans still typically far outperform AI on such tasks. Developing an AI that can match or exceed human driving performance is "one of the most complex and challenging AI problems still unresolved" (Gingras, 2017).

AI approaches applied to autonomous vehicles include machine learning methods, such as deep learning and reinforcement learning (Ma *et al.*, 2020). In these approaches, computers learn to perform a certain task without being explicitly programmed to do so. Instead, the computer can self-modify the algorithms and statistical models that they use to make a prediction. Machine learning requires a human intervener to assess and report the accuracy of the prediction (Grossfeld, 2020). Deep learning, a subtype of machine learning, enables the computer itself to evaluate the accuracy of its prior predictions and adjust accordingly (i.e., recognize and learn from its own mistakes) (Grossfeld, 2020). For autonomous vehicles, computers use vast amounts of recorded and stored sensor data from vehicles operated by human drivers and AI-controlled vehicles, as well as from simulations. Challenges in the design, training, and testing of AI for automated driving include the wide variety of sensor data being used among different stakeholders that are generating datasets of different types, quality, reliability, and availability (Ma *et al.*, 2020). Challenges also arise in handling the complexity and uncertainty associated with perception and decision-making tasks; the complexity of tuning models for real-time (i.e., instantaneous) decision-making; and the computational resources (i.e., hardware) needed for these applications (Ma *et al.*, 2020). Some of the most advanced machine learning approaches (such as deep learning neural networks) perform too poorly for safety-critical situations such as driving (Gingras, 2017; Ma *et al.*, 2020). Thus, while SAE Level 4 vehicle development will most likely continue apace and operational domains will expand over time, predicting when fully autonomous, SAE Level 5 vehicles will appear that can operate on all roads and under all conditions is much more uncertain.

2.3 Shared Vehicles

Shared mobility "provides users with short-term access to a travel mode on an as-needed basis" (SAE, 2020). Given the high initial costs of technology, the Panel made the working assumption that, at least in the next decade, autonomous vehicles will be available largely through some form of shared mobility, rather than purchased individually as personal vehicles. Cars today may spend 95% of their time parked (Shoup, 2005). Autonomous vehicles capable of operating without drivers or passengers could spend their time travelling empty to run errands (e.g., delivering a grocery order), or simply driving to avoid the cost of parking (Schwartz, 2018). The ability to travel empty creates an opportunity to use downtime productively by providing rides to other people or delivering goods, though such opportunities may be constrained by travel patterns (e.g., morning and afternoon commutes). One of the main speculations about CASE vehicles is the potential shift away from personal vehicle ownership as people prioritize buying rides instead of vehicles. Shared mobility services will likely affect the acceptance, usage, and availability of CASE vehicle technology on roads in Canada (Box 2.2).

Box 2.2 Shared Mobility Services Available Today Relevant to CASE Vehicles

Shared mobility services that could use CASE vehicle technology include:

Mobility-as-a-Service. An integrated mobility solution using a single interface (e.g., a smartphone app) to meet users' transportation needs through multiple mobility options (public transit, car sharing, ride hailing, etc.), all paid for through a single account, e.g., UbiGo (Sweden) and MaaS Global (Finland).

Ride hailing (ride sourcing). Smartphone apps connect paying passengers with drivers who provide rides in their private vehicles. Service providers design and operate the apps, e.g., Uber and Lyft (United States and Canada). *Ride pooling* is a variant in which passengers share rides to split the cost, e.g., UberPool.

Ride sharing (carpooling). Private vehicle owners arrange to share rides on short notice between common origins or destinations. A type of carpooling facilitated by online platforms that charge a fee for making connections, e.g., BlaBlaCar (Europe and South America) and Waze (United States).

(Continues)

(Continued)

Car sharing. Short-term car rentals (i.e., by the hour). Users have unattended access to vehicles through electronic systems. Gasoline and insurance are typically included in the service. Car sharing business models include:

- **Round trip** – Reservation from beginning to end, vehicle returned to home station, e.g., Zipcar and Turo (United States and Canada)
  - Peer to Peer: private individuals own the fleet
  - Business: companies own the fleet, station-based
  - Corporate: corporate fleets with telematics and online scheduling
- **Flexible** – One-way or on-demand services, e.g., Communauto (Canada)
  - Free floating: vehicles returned to any valid parking spot within specified area
  - Station-based: vehicles returned to designated parking spaces

Micromobility (bicycle and scooter sharing). The use of very light vehicles for transportation, such as bicycles or electric scooters, e.g., BIXI bicycles and Lime e-scooters (Canada).

Microtransit. Privately or publicly operated technology-enabled transit service typically using multi-passenger or pooled shuttles or vans to provide on-demand or fixed-schedule services with either fixed or dynamic routing, e.g., Para Transpo (Canada) and ViaVan (Europe).

CAR (2016), CBC News (2019a), SAE (2020), ViaVan Technologies B.V. (2020)

Many experts predict a future with shared, connected, and autonomous vehicles — owned by companies and used on demand by customers — as the most likely scenario, given the rise of shared mobility today and the predicted high expense of the first commercially developed autonomous vehicles (McKinsey & Company & BloombergNEF, 2016; Spulber *et al.*, 2017; Botello *et al.*, 2018; Seuwou *et al.*, 2020). A MaRS Solution Lab report, informed by input from Canadian experts, private companies, municipalities, and civil society organizations, concluded that shared mobility (described as a system of shared vehicles and public transit) is a desirable trend for the City of Toronto, with the potential to reduce costs, congestion, and the environmental impacts of transportation (Sim *et al.*, 2019).

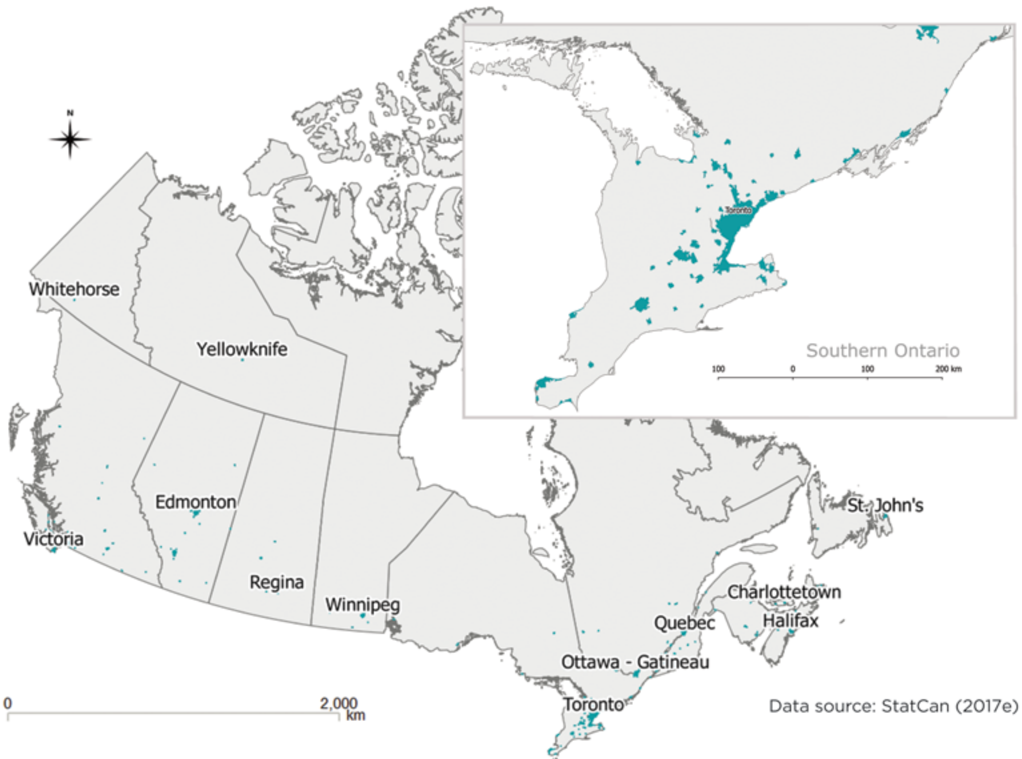


Figure 2.2 Areas of Urban Density Potentially Capable of Supporting a Fleet of CASE Vehicles in Canada

Areas in teal represent census blocks that are greater than 13 km^2 with populations greater than 10,000 and a minimum population density of 400 people/km^2. Inset is a close-up of southern Ontario as an illustrative example of the limited number of areas with high population densities even within heavily populated parts of Canada.

2.3.1 Shared Mobility in the Next 10 Years

The ways in which policies and regulatory decisions made today regarding shared mobility will shape the future of CASE vehicles in Canada are probably less about timing and more about location. Based on U.S. transportation models, Burns and Shulgan (2018) estimate that communities with population densities greater than 288 people per square kilometre (750 per square mile) can host a well-performing mobility system based on shared autonomous vehicles. For example, for a population of 285,000, a fleet of 18,000 autonomous vehicles can replace 200,000 personally owned vehicles and still achieve wait times for rides of less than one minute, thus reducing the number of vehicles in the overall fleet by an order of magnitude (Burns *et al.*, 2012).

In 2016, Canada's average population density was 3.9 people per km^2 (StatCan, 2017d). A large proportion of the land mass is uninhabited, and the population is not evenly distributed. There were 1,015 population centres in Canada in 2016, areas where densities exceed 400 people per square kilometre, ranging in size from 0.18 km^2 (St. Theresa Point, Saskatchewan: population 1,038) to 1,792.99 km^2 (Toronto, Ontario: population 5.43 million) (StatCan, 2017d). Therefore, over 1,000 communities in Canada could be viable hubs for mobility systems based on autonomous, shared vehicles according to the results of the Burns and Shulgan (2018) model. However, of the 286 population centres in Ontario (StatCan, 2017d), only 66 municipalities had urban transit in 2015 (CUTA, 2016). The smallest service area in Ontario was 13 km^2 (Cobourg), while the smallest service population was 7,000 (Kenora) (CUTA, 2016). Taken together as a rough estimate, if it is reasonable to expect that a municipality would need a population of at least 10,000 and a service area of at least 13 km^2 to consider deployment of a fleet of CASE vehicles as a transportation service, the number of expected deployment areas would be reduced to 162 population centres across Canada (Figure 2.2). Based on 2016 census data, this service would cover roughly 70% of the population in Canada (StatCan, 2017e).

It will take multiple decades to transition from personal vehicle ownership to shared mobility

Even in densely populated areas, it may take more than a decade for Canadians to replace their personally owned vehicle with alternative mobility options. The average age of a personal vehicle in Canada in 2015 was 9.62 years, an increase of 16.2% in age since 2010 (Canadian Fuels Association, 2017). Both Europe and the United States have also shown increases in the average vehicle age of passenger cars: from 2007 to 2015, the average age increased by 27% in Europe (Ciferri, 2017), and by around 12% in the United States (BTS, n.d.). Moreover, the availability of shared mobility services, even if inexpensive and convenient, may not be enough for most car owners to abandon ownership entirely, particularly not until a variety of vehicle types are available, and a majority of consumers are confident in their reliability, comfort, cost, and convenience (Grush & Niles, 2018). Such a mobility system would rely not only on CASE vehicle technology, but also on the coordinated orchestration of vehicle fleets among governments, planners, private industry, and consumers; complexity in planning and regulatory decisions may limit the deployment of CASE vehicles even as technological challenges are met (Grush & Niles, 2018).

The establishment of shared mobility services such as ride hailing (ride sourcing) in cities is negatively associated with vehicle ownership (e.g., Ward *et al.*, 2019; Sabouri *et al.*, 2020). Though a long-term potential impact of shared vehicles on the automotive industry is a reduced demand for new vehicle production, such an impact is not likely to be felt for some time yet, if at all. CAR (2016) projected sales losses of around 137,500 units due to car-sharing programs in the United States between 2010 and 2021; this would represent about 0.25% of all new and used vehicle sales over that time period. Decreases in private individual purchases may be offset by increasing demand from car-sharing fleet operators, especially if their competitiveness hinges on having newer and more attractive vehicles (CAR, 2016).

2.4 Electric Vehicles

The Panel concurs with the widely held assumption that many or all connected, autonomous, and shared vehicles will also be electric vehicles (EVs). The main areas where EVs do not compare favourably to their internal combustion engine (ICE) counterparts (i.e., diesel- and gasoline-fuelled) are price, driving range, lack of recharging infrastructure, and long recharging times (Andwari *et al.*, 2017; AAA, 2019). However, examining the total lifecycle costs of EVs shows that they are cost-competitive with ICE vehicles for about a fifth of Canadian households, based on factors such as annual mileage, level of urbanization, household income, and ownership period (Abotalebi *et al.*, 2019).

2.4.1 Electric Vehicles in the Next 10 Years

Global sales of EVs neared two million in 2018, an increase of 68% over 2017 sales (IEA, 2019). Estimates of the widespread adoption of EVs vary, though stakeholders such as Bloomberg New Energy Finance, the Organization of the Petroleum Exporting Countries (OPEC), and British Petroleum (BP), among others, expect total EVs on roads to meet or exceed 100 million globally in the early 2030s (CEC, 2017). The tipping point for EV deployment will most likely occur when the price reaches parity with gasoline-powered vehicles (CEC, 2017). Although EVs initially cost more than conventional ICE vehicles, the operating and maintenance costs are lower for EVs (Palmer *et al.*, 2018; Morgan, 2019). However, the depreciation of EVs is also not well understood in comparison to conventional vehicles and is therefore often excluded from such analyses (e.g., Palmer *et al.*, 2018; Weldon *et al.*, 2018).

In 2018, EVs accounted for 2.2% of all passenger vehicle sales in Canada, up from 1.4% in 2017 (EMC, 2019). In Budget 2019, the Government of Canada proposed to invest $300 million over three years on purchase incentives of up to $5,000 for some zero-emissions vehicles (TC, 2019g), which include EVs as well as hybrids and vehicles powered by hydrogen fuel cells (TC, 2019i). The federal government has also set the following aspirational targets for zero-emission light-duty vehicle sales: 10% by 2025, 30% by 2030, and 100% by 2040 (TC, 2019g). Urban electric buses (e-buses) are the most successful segment of the EV market worldwide. The demand for clean tech in public transportation comes from a combination of political influence, customer demand (i.e., public transit operators and city governments), and government subsidies (Heid *et al.*, 2018). Ninety percent of new urban buses sold in China in 2017 were fully electric, and the European Commission has proposed a target of 75% e-buses in transit operations in Europe by 2030 (Heid *et al.*, 2018). B.C. Transit announced the target of a fully electric bus fleet by 2040 and similar commitments to fully electric fleets have previously been announced in Montréal and Toronto (CBC News, 2019b).

The availability of charging stations has a tremendous influence on the uptake of EVs in Canada. More than 4,300 EV charging stations were operating in Canada as of September 2018 (NRCan, 2018), compared with 11,929 retail gas stations (Kent Group Ltd., 2019). The Electric Vehicle Chargers Ontario program led to the installation of 346 public charging stations across the province before its cancellation in 2018 (Gov. of ON, 2018; Xing, 2019). At the federal level, the Government of Canada is investing $96.4 million in EV and alternative fuel infrastructure to develop a coast-to-coast charging network, $76.1 million to "support the demonstration of next-generation charging technologies," and $10 million in the development of codes and standards for low-carbon vehicles and infrastructure consistent across the United States and Canada (GC, 2019b).

2.4.2 The High Cost of Batteries

Batteries are the main bottleneck in EV technology due to their state of technological development and cost. Current lithium-ion batteries used in EVs have several shortcomings related to stability, cycle life (the number of charge/discharge cycles the battery can support), and operational temperature range (AAA, 2019). Batteries are also the most expensive component of an EV (CEC, 2017), making them one of the main barriers to EV deployment (Andwari *et al.*, 2017).

However, numerous promising developments in battery technology are currently being explored, such as lithium air batteries (Andwari *et al*., 2017). Costs also are being reduced, dropping by 87% between 2010 (over US$1,100/kWh) and 2019 (US$156/kWh) because of technological improvements, economies of scale, and growth in EV sales (BloombergNEF, 2019). A 2020 announcement from GM Canada promises further cost reductions to below US$100/kWh (GM Canadian Corporate Newsroom, 2020). Battery leasing programs may also help reduce customer anxiety over battery cost and depreciation, while boosting profitability of EVs for manufacturers (Baik *et al*., 2019).

The limited driving range of current EVs is another significant issue (Andwari et al., 2017). Although most current EVs can travel over 200 km on a single charge (PND, n.d.), slow charging times and a general lack of charging infrastructure present a significant obstacle to their widespread adoption. Furthermore, temperature — particularly cold temperatures — can affect battery performance, resulting in reduced driving range. In one study, relative to a baseline ambient temperate of approximately 24°C, an ambient temperature of approximately -7°C resulted in a 12% reduction in driving range, and the use of heating, ventilation, and air conditioning (HVAC) at temperatures of approximately -7°C led to a 41% reduction in driving range (AAA, 2019).

2.5 Sequence of Adoption for CASE Vehicles

Settling on a timeline for widespread CASE vehicle adoption in Canada is fraught with uncertainty; however, given the observed use of these new technologies outlined above, the Panel considers the sequence of adoption to be clearer:

- SAE Levels 1 and 2 automation are already available in some personal vehicles.
- Equivalents to SAE Levels 3 and 4 automation are already in use in applications such as mining and farming.
- Automated driving in heavy commercial transportation is likely to arrive in the next 10 years, with platooning applications and automated driving tested today in transport trucks.
- Autonomous low-speed shuttles and other public transit applications are likely to arrive in the next 10 years, along with pilots of robo-taxis.
- Level 5 autonomous vehicles on public roads are not going to arrive in the next 10 years;[3] they will likely diffuse through shared ownership models, in mobility service applications (e.g., taxis or ride-hailing fleets), and through light commercial applications (i.e., delivery services).

3 The Panel notes there is uncertainty around whether Level 5 will ever be possible.

Speculating about the timing of personally owned autonomous vehicles on Canadian roads is difficult due to the complexity of possible outcomes and applications (e.g., shared vs. privately owned, commercial vehicle uses, internal combustion costs vs. electrification, infrastructure requirements) coupled with uncertainty about important technical bottlenecks (e.g., battery life, AI, sensors, V2X). While technical challenges for fully autonomous vehicles on public roads are relatively well understood, the implications for road regulations, vehicle safety standards, costs, consumer acceptance, and ethical standards are unclear and may limit their eventual use. Despite technological challenges to the widespread commercial deployment of autonomous vehicles, SAE Level 4 automation is achievable. These vehicles must be able to operate autonomously only in certain conditions (such as within a geographical area or on certain types of roads), and, as technology improves, so too will the breadth of areas where these vehicles can operate. SAE Level 5 automation may not be attainable, as it requires operation in any driving situation. However, regardless of technological advances, social acceptability, trust in the safety and security of new technologies, and the resultant government regulations may present greater barriers to the widespread use of highly autonomous vehicles.

Consumer acceptance of autonomous vehicles may be low in Canada

Canada ranks 13th out of 30 countries in consumer acceptance of connected and autonomous vehicles in KPMG's (2020a) *Autonomous Vehicle Readiness Index*, down from 11th out of 25 countries in 2019 (KPMG, 2019). Although the results of public polling on the topic are inconsistent, some general trends emerge: in a number of recent public opinion surveys, Canadians have expressed some reservations about autonomous vehicles, with fewer than 30% of respondents saying they would want to own or use one (e.g., Gillis, 2016; CP, 2017; Ipsos, 2018). According to a 2018 Ipsos survey, Canada has one of the highest rates of resistance to autonomous vehicles, and Canadians were more likely to say they would not use a self-driving car and were less interested in owning one or sharing one compared with the rest of the world. Fewer than 50% of Canadians surveyed thought that autonomous vehicles would be safer or more economical than conventional cars. However, Canadians trust government to regulate these vehicles more than they trust manufacturers, insurance companies, or automobile and motorist associations; in the rest of the world, this is reversed (Ipsos, 2018).

Regulatory authority and enforcement requirements for CASE vehicles are complex

SAE Level 4 automation is most likely to be in commercial use under limited, geo-fenced conditions, such as within freight terminals or port facilities (Perlman *et al.*, 2018), as is the case with New York City's first self-driving shuttle service (Hawkins, 2019b). Several gaps in safety regulations need to be addressed before autonomous commercial motor vehicles are deployed on U.S. roads (Perlman *et al.*, 2018). These include the need to refine the definitions of "driver" and "operator," and to determine the level of training, licensing, and operating requirements for either an onboard technician or a remote supervisor responsible for the safe operation of autonomous commercial motor vehicles. Additionally, there are gaps in regulations on safe driving qualifications for the automated driving system itself and in identifying standards for ensuring the safe performance of physical systems and the inspection and maintenance of equipment on autonomous vehicles (Perlman *et al.*, 2018).

Similar gaps are present in Canadian regulations, with some additional jurisdictional complexity, as the responsibility for commercial vehicle safety and licensing is divided between the federal, and the provincial and territorial authorities respectively (TC, 2019h). Policy and regulatory challenges for autonomous vehicle deployment include vehicle design and performance standards, updates to insurance laws, as well as issues surrounding the development of technical standards for autonomous and connected vehicle technology. A degree of international harmonization of regulatory standards is required to ensure the cross-border interoperability of autonomous vehicles. Ultimately, many experts expect that technology will likely outpace regulation, such that the largest barrier to deployment will not be technological, but rather public acceptance and supportive policies, laws, and regulations (SSCTC, 2018).

In Canada, federal, provincial and territorial, and municipal governments share responsibility for regulating motor vehicle transportation (Table 2.3). In 2019, Transport Canada released *Canada's Safety Framework for Automated and Connected Vehicles* to provide guidance on safe testing and deployment. Other documents complement this framework. *Testing Highly Automated Vehicles in Canada: Guidelines for Trial Organizations* (2018) clarifies the roles of different levels of government and sets voluntary minimum safety requirements for vehicle trials. Provincial and territorial governments can set their own laws and regulations, building on these minimum voluntary requirements and approving requests for trials. The *Canadian Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles*, jointly released in 2018 by the provinces and territories and Transport Canada, provide guidance on issues relating to testing and deployment, including vehicle registration, trial programs, driver training, and enforcement of traffic laws (CCMTA, 2018). The *Safety Assessment for Automated Driving Systems in Canada*, released in 2019, provides guidance to manufacturers on safety issues related to SAE Level 3 and above that are not currently addressed in regulations (TC, 2019c). While the use of guidelines and frameworks allows for adaptation and responsiveness to changing technologies, ultimately statutes and regulations will need to be amended, or new legislation enacted, to ensure the enforceability of critical safety, privacy, and security requirements for CASE vehicles.

Table 2.3 Canadian Government Roles and Responsibilities Relating to Road Transportation and CASE vehicles

Federal
• Leads the harmonization of regulations across Canadian jurisdictions, including regulations for pilot testing systems • Facilitates collaboration among all levels of government and industry • Holds vehicle manufacturers accountable for compliance with safety standards and technology standards internationally, particularly in the United States and Mexico • Sets and enforces motor vehicle safety standards • Develops rules relating to privacy and cybersecurity • Sets and enforces technical standards for communication technology (e.g., 5G, DSRC) • Provides funding for industry and academia (e.g., research, expanding production capacities)
Provincial and territorial
• Develops legal framework for vehicle testing and deployment • Enacts legislation incorporating federal vehicle safety requirements • Manages driver licensing and vehicle registration • Regulates vehicle insurance and liability • Sets and enforces traffic laws and regulations • Adapts provincially owned transportation infrastructure to support CASE vehicles • Develops and plans future transportation projects • Provides funding for industry and academia (e.g., research, expanding production capacities)
Municipal
• Enforces legislative and regulatory framework created by provinces and territories, including for CASE vehicle safety enforcement • Enacts and enforces municipal bylaws related to transportation • Adapts municipally owned transportation infrastructure to support CASE vehicles • Makes land use and urban planning decisions • Operates transit systems including public transit, taxis, and MaaS • Manages logistics of traffic control and parking enforcement

Adapted from PPSC (2019)

CASE vehicle technology is anticipated and supported in some areas in Canada

There is broad anticipation and support for the development of CASE vehicle technology in Canada (Box 2.3). Pilot projects using low-speed autonomous shuttles have moved people on public and private roads in Canada, for example, in British Columbia, Alberta, and Quebec (ELA, 2018; Transdev Canada, 2019). Provincial and territorial governments have set their own requirements for autonomous vehicle deployment by approving requests for trials, either through legislation (e.g., Gov. of QC, 2018; Gov. of ON, 2019a) or by granting exemptions from applicable traffic regulations (e.g., Heinsen & Makson, 2019). In 2019, the City of Toronto released its Automated Vehicles Tactical Plan, preparing for the appearance of highly autonomous vehicles on city streets in 2022 (City of Toronto, 2019a).

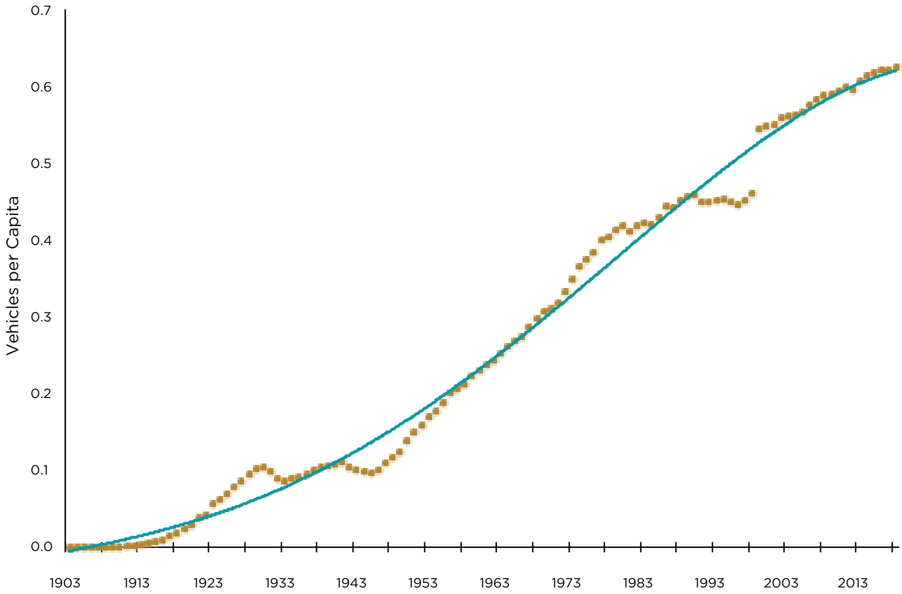
Box 2.3 Funding Programs that Support CASE Vehicle Development in Canada

Federal funding programs that support CASE vehicle development in Canada include general funds to support innovation (i.e., the Strategic Innovation Fund and the National Research Council of Canada Industrial Research Assistance Program) as well as support through the Natural Sciences and Engineering Research Council, which provides grants to university researchers (TC, 2019e). The Canada Foundation for Innovation provides infrastructure grants to research facilities, including laboratories studying automated driving (e.g., CFI, 2017). Targeted regional supports include the Federal Economic Development Agency for Southern Ontario (FedDev Ontario), intended to help secure and strengthen the economy (TC, 2019e).

Provincial governments are also actively supporting the CASE vehicle industry. In Ontario, for example, the Autonomous Vehicle Innovation Network (AVIN) supports programs to develop and demonstrate automated driving technology through support from the Ontario Ministry of Economic Development, Job Creation and Trade, and the Ministry of Transportation through Ontario Centres of Excellence (AVIN, 2019). Propulsion Québec supports “positioning Quebec as a global leader in developing and implementing smart and electric modes of ground transportation,” with financial support from the Province of Quebec as well as federal and municipal governments (Propulsion Québec, n.d.).

CASE vehicles will likely follow an s-shaped diffusion path

The first affordable car, Ford's Model T, began production in 1908, but it took until the 1990s for the automotive market to reach saturation in the United States, with about four out of five people owning a vehicle (Litman, 2019). In Canada, the diffusion of the automobile followed a similar curve, reaching a point where about three out of five people owned a vehicle in 2018 (Figure 2.3). This s-shaped diffusion path is typical for many automotive technologies. Automatic transmissions (available for the past 50 years), airbags (25 years), and navigation systems (30 years) have all followed an s-shaped diffusion path to saturation at 80 to 100% market share (Litman, 2019). Other automotive technologies, such as hybrid vehicles and subscription services (e.g., navigation, remote lock and unlock, emergency), have market shares below 5% (Litman, 2019). As shared mobility services offer new mobility options for people in Canada, it is difficult to predict the eventual market penetration of personally owned autonomous vehicles. However, since the individual benefits depend on how many other people use them (i.e., positive network effects), diffusion may follow a path similar to other network technologies such as the internet, smartphones, and social media (e.g., Brynjolfsson & McAfee, 2014; Naughton, 2016; Reid, 2018).



Data sources: StatCan (2014, 2019c, 2019h)

Figure 2.3 Automobile Diffusion Path in Canada

The number of light vehicles per capita in Canada roughly follows an s-shaped diffusion curve (teal line), with an inflection point somewhere in the 1970s. Note that a change in the way vehicles were classified in 2000 (from "passenger automobiles" to "vehicles weighing < 4,500 kg") disrupts the flow of the curve.

Consumers who are early adopters have a high willingness to pay for autonomous vehicles due to their optimism about the technology (Shabanpour *et al.*, 2018; Talebian & Mishra, 2018). These early adopters are likely to have high levels of income, education, and technological literacy (Shabanpour *et al.*, 2018). As noted above, consumers are motivated by different modes of communication. For example, frequent long-distance travellers are more driven by advertising than people who have experienced a collision; the latter tend to be more influenced by word of mouth (Shabanpour *et al.*, 2018). Interestingly, the price of autonomous vehicles relative to conventional vehicles does not show a strong effect on their demand (Lavasani *et al.*, 2016). With the price of autonomous vehicles expected to decline steeply over time, social factors are likely to be stronger drivers of diffusion than economic considerations.

There is some consensus that autonomous vehicles will not become commonplace on public roads in Canada until the 2030s or 2040s (Ticoll, 2015). Many predict worldwide early adoption to begin by 2030, peaking in the 2040s and reaching saturation of the automobile market share in the 2060s (e.g., Lavasani *et al.*, 2016; Shabanpour *et al.*, 2018; Talebian & Mishra, 2018). The rate of adoption will likely occur sooner within cities (i.e., within 10 to 15 years) and later in areas between cities (20 to 30 years) (SSCTC, 2018).

2.6 Summary

Connected vehicles and electric vehicles are on roads today and are growing in number. Similarly, SAE Level 1 and 2 technologies are available today on most new vehicles in Canada. Private commercial applications for autonomous vehicles are already occurring in mining and agriculture, and on private industrial campuses; these will likely expand to warehouses, ports, and other facilities with private roads within the next five years. In the next 10 years, public commercial applications in trucking and delivery services are likely to continue, as well as applications in mobility services such as low-speed autonomous shuttles and public transit vehicles. Autonomous personal vehicles are the furthest away in time, with the greatest uncertainty about the timing of their arrival, though they are most likely to arrive through shared mobility models. Uncertainties stem from technological challenges such as AI, computing power, and sensors; regulatory challenges including insurance and safety standards; and social challenges such as acceptance and affordability. Any one of these uncertainties may limit the deployment of fully autonomous personal vehicles. The most likely scenario, and the Panel's working assumption throughout the report, is that vehicle technology trends are moving towards a combined CASE vehicle.

3

CASE Vehicles and Industry

Chapter Findings

- CASE vehicles create opportunities for R&D expansion in the automotive industry, though it is unclear whether Canada will be able to attract and maintain R&D investments from both international and domestic firms.
- Securing production mandates for Canadian plants for CASE vehicles and component parts will be important to offset the sector's current struggles but will require ongoing engagement from federal and provincial governments.
- The vertically integrated supply chains of the automotive sector are expected to restructure to reflect the network organization of the ICT sector, creating opportunities for companies in infotainment, gaming, aftermarket services, financial services, delivery services, fleet management, and shared mobility services. A substantial challenge for the Canadian ICT and automotive industries is how to integrate into CASE vehicle supply networks, particularly in the next 10 years.
- The electrification of transit and commercial vehicle fleets present opportunities for expansion among Canadian bus and commercial vehicle manufacturers.
- In the longer term (i.e., beyond 10 years), the business model of automotive companies will face disruption if their value proposition shifts from selling cars to selling rides (or the ride experience).

The automotive industry in Canada is a complex system comprising parts suppliers (from raw materials to assembled components), vehicle manufacturers (also called original equipment manufacturers or OEMs), dealers, independent service garages, and consumers. As new technologies emerge, the economy progresses by combining them into new products and processes with new functionalities (Arthur, 2009). CASE vehicles combine traditional automotive manufacturing and assembly with software development, service management, AI, sensors, and other technologies in the network economy. Magna, founded in Toronto in 1957 and one of the largest automotive parts suppliers in the world, now bills itself as a technology company that supplies to the automotive industry (Magna International Inc., 2019). CASE vehicles are likely to cause OEMs to shift their focus from hardware to software development (McKinsey & Company & BloombergNEF, 2016). Currently, automotive OEMs typically have an 11:1 ratio of hardware to software engineers, compared with a 1:2 ratio at tech companies (McKinsey & Company & BloombergNEF, 2016). CASE vehicles will create a network of opportunity niches directly related to manufacturing, assembly, and operation. Other sectors, such as alternative fuels for transportation (Bicer & Dincer, 2018) and the fashion industry (e.g., Stein, 2019), may also be indirectly affected by CASE vehicle development. At their core, CASE vehicles will still be vehicles, requiring a vehicle and parts manufacturing supply chain and assembly capabilities. This chapter considers the extent to which Canadian manufacturing may be an integrated part of the CASE supply chain, and how the integration of other technology sectors will affect Canadian industry (Figure 3.1).

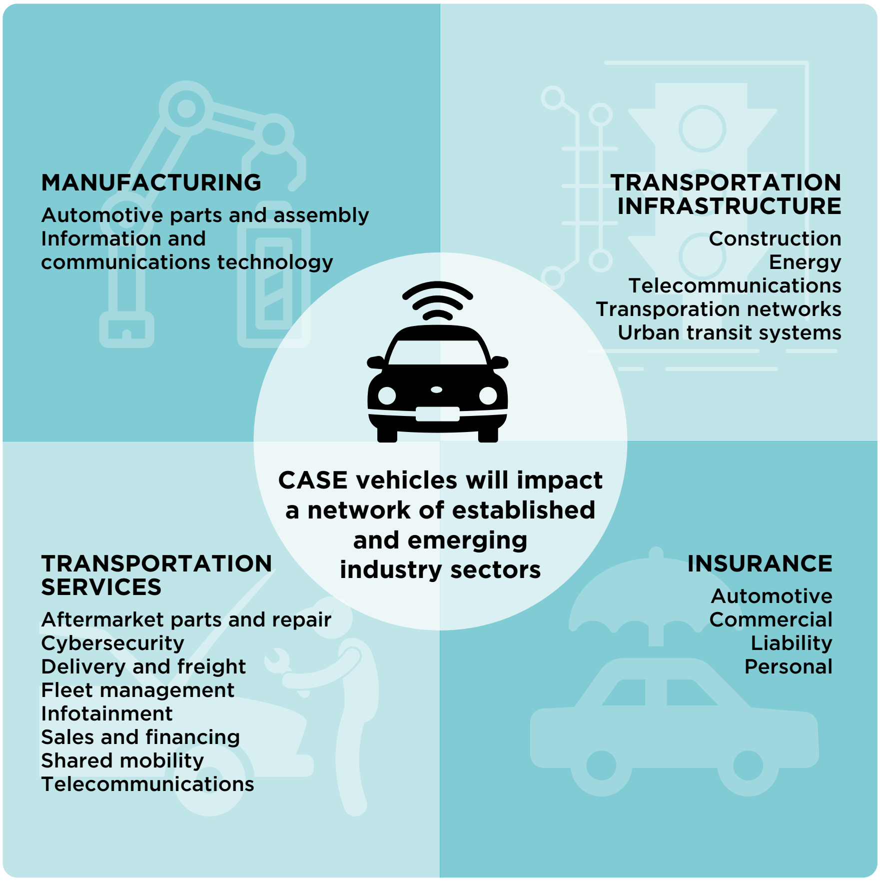


Figure 3.1 Industry Sectors Impacted by CASE Vehicles

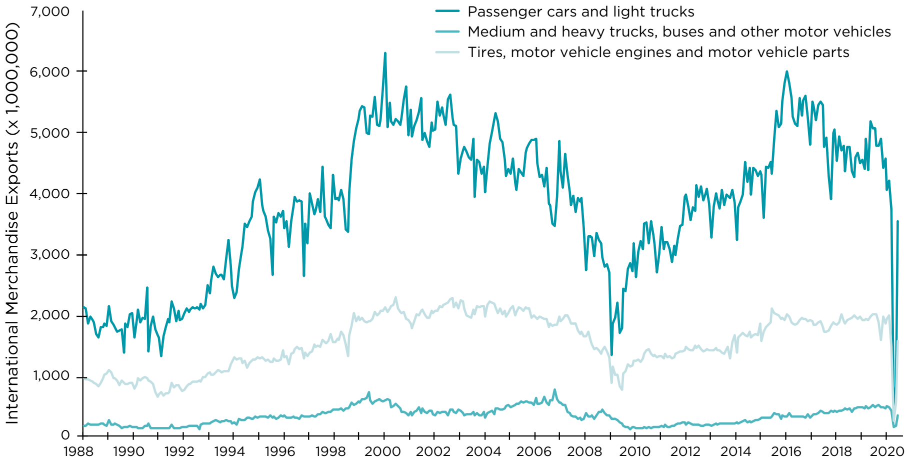
Connected, autonomous, shared, and electric (CASE) vehicles will have impacts across a network of established and emerging industry sectors, including those related to automotive and information and communications technology (ICT) manufacturing, transportation infrastructure, transportation services, and insurance.

3.1 Motor Vehicle and Parts Manufacturing

Motor vehicles and parts manufacturing is currently Canada's second largest manufacturing industry (Yates & Holmes, 2019), employing around 145,000 people directly and adding $16.4 billion to Canada's GDP in 2019 (StatCan, 2019f, 2019g).[4] None of the five OEMs building light vehicles in Canada — Toyota, Fiat Chrysler Automobiles (FCA), GM, Honda, and Ford — are domestically owned (Yates & Holmes, 2019). They operate seven assembly plants across southern Ontario and employ around 28,000 people (FCA, 2019; TMMC, 2019; Honda Canada Inc., 2020; Ford, n.d.; GM, n.d.).

The Canadian automotive industry is tightly interwoven with those of the United States and Mexico. Approximately 85% of light vehicles built in Canada were exported to the United States in 2016; conversely, Canada imports around 45% of its light vehicles from the United States, with an additional 12% coming from Mexico (Yates & Holmes, 2019). Canada's export of motor vehicles and parts has largely recovered from the 2008 financial crisis (Figure 3.2). However, light vehicle production (i.e., passenger car production) has not recovered to the same level, with production in 2019 at 28% of the 1999 peak (OICA, 2020). Around 700 parts suppliers in Canada support motor vehicle manufacturing, both domestically and abroad (Tanguay, 2018). Four OEM parts suppliers based in Canada (all in Ontario) ranked in the top 100 globally in 2018 based on sales of original equipment parts: Magna International Inc. in Aurora (ranked third); Linamar Corp. in Guelph (57th); Martinrea International Inc. in Vaughan (78th); and Multimatic Inc. in Markham (93rd). Collectively, they accounted for more than $49 billion in OEM automotive parts sales in 2018 (Automotive News, 2019a).

4 These figures exclude workers employed by temp agencies and some parts suppliers that supply automotive firms (e.g., glass, rubber, and foundry products). They also include manufacturers of heavy trucks, motorcycles, military, and other vehicles not generally considered part of the automotive industry. Using a different methodology, Sweeney and Mordue (2017) estimated that, in 2014, the automotive industry employed at least 130,000 people in Canada, 124,000 of which were located in Ontario.



Data source: StatCan (2020)

Figure 3.2 Export of Motor Vehicles and Parts from Canada, by Month

Seasonally adjusted, customs-based monthly exports (x 1,000,000) of motor vehicles (passenger cars and light trucks; medium and heavy trucks, buses, and other motor vehicles; tires, motor vehicle engines, and motor vehicle parts) in Canada, from January 1988 to June 2020. X-axis labels indicate data from January of that year.

3.1.1 The State of Motor Vehicle and Parts Manufacturing in Canada

Motor vehicle and parts manufacturing is declining in Canada

As with manufacturing jobs worldwide (Gruss & Novta, 2018), motor vehicles and parts manufacturing has declined in Canada in the last 20 years. The decline of Canada's automotive industry since the early 2000s is a result of multiple compounding factors. These include the end of the *Canada-United States Automotive Products Agreement* (the Auto Pact) of 1965, the appreciation of the Canadian dollar, and increased competition from lower-wage regions in the southern United States and Mexico (Mordue & Sweeney, 2017). Mordue and Sweeney (2019) place Canada in the semi-periphery of automotive manufacturing — neither the core (near OEM headquarters), nor the integrated periphery (with low-cost production facilities owned by foreign OEMs). The industry features high levels of foreign ownership, no domestic OEMs, and high production costs, but includes large, multinational auto parts suppliers. Government incentives today support the maintenance and upgrading of existing facilities, but have not attracted much in the way of new builds or growth (Mordue & Sweeney, 2017).

The competitiveness of Canadian motor vehicle and parts manufacturing depends on the relative value of factors such as cost and quality of labour, energy, logistics, and other input costs, compared with North America and the rest of the world (e.g., CAPC, 2016). For example, while labour costs in Canada and the United States were similar in the first quarter of 2020 (112 to 114 index points, respectively), the cost of labour in Mexico averaged 14.5 index points lower than Canada (Trading Economics, 2020). Trade agreements also influence Canada's competitiveness. Impacts will likely differ for OEMs and Tier 1 suppliers as compared to small and medium-sized manufacturers. Some uncertainty exists, however, about the impact of newer trade agreements, which are yet to be ratified or fully implemented, on the future of automotive manufacturing (Yates & Holmes, 2019). Recent legislation seeking to reduce business costs, harmonize regulatory requirements, and reduce barriers to investment has attempted to address the regulatory burden for businesses operating in Ontario (Gov. of ON, 2019b).

Canada has notable strengths in automotive manufacturing, such as award-winning vehicle production facilities, a highly educated and skilled workforce, and multiple automotive R&D facilities in government labs and university and college campuses (Tanguay, 2018). J.D. Power (2019) awarded the Platinum Plant Quality Award to Toyota Motor Corp.'s Cambridge North plant in 2019 for producing vehicles with the fewest defects and malfunctions in the world. As well, J.D. Power's highest ranked compact utility vehicle in 2019 was the Chevrolet Equinox, built by GM at their plant in Ingersoll, Ontario (Irwin, 2020). However, the relative quality and education levels of the automotive workforce in Canada may be more comparable to lower-cost regions than is generally acknowledged (Mordue & Sweeney, 2017). While the education of the Mexican workforce is, on average, much lower than in Canada, OEMs in Mexico are attractive employers recruiting from pools of candidates that include skilled and educated workers (Mordue & Sweeney, 2017).

Respondents to a 2015 survey of automotive parts manufacturing plant managers in Ontario (115 of 558 surveyed, which included Canadian and foreign-owned plants ranging in size from < 50 to > 250 employees) felt that payroll taxes and electricity costs were the greatest barriers to plant success (Holmes *et al.*, 2017). The majority of respondents thought that public policy measures, such as subsidies and tax credits for R&D, programs to retain or attract vehicle assembly capacity, international trade agreements, and support for workforce training, contributed to plant success (Holmes *et al.*, 2017). These survey results also reflect the described challenges of exiting the semi-periphery — that is, manufacturing plants may either try to compete in the integrated periphery (e.g., with low-cost areas like Mexico and the southern United States) or attempt to move towards knowledge-based activities (e.g., R&D) traditionally located within the core of the industry (Mordue & Sweeney, 2019).

Automotive R&D is largely performed outside of Canada

Globally, the automotive industry ranks as medium to high R&D intensity (Galindo-Rueda & Verger, 2016). In Canada, however, the domestic automotive industry ranks among the least R&D-intensive industries, investing at only about 12% of the OECD average and less than 6% of world-leading Japan (CCA, 2018). Specifically, in 2011, Canada ranked 26th out of 29 countries in R&D intensity in the motor vehicles, trailers, and semi-trailers industry (CCA, 2018).

Canada's automotive sector is comprised of mostly part suppliers and OEM assembly plants; these types of facilities perform much less R&D than do product engineering facilities, which, in North America, are typically co-located with OEM headquarters and clustered in Michigan (Yates & Holmes, 2019). Canada generates less than 2% of the global share of vehicle-related patents (i.e., B60 patents) produced by the five OEMs and their subsidiaries operating here (Mordue & Sweeney, 2019). However, Mordue and Sweeney (2019) note that using patent activity as a proxy for R&D activity presents shortcomings, particularly because process-oriented innovations are often managed as trade secrets rather than submitted as patents in the automotive industry. As well, there is evidence that automotive R&D is increasing in Canada. Ford and GM have notably increased their patent activity in Canada in recent years (Mordue & Sweeney, 2019) and both have announced expansions in R&D facilities in southern and eastern Ontario, respectively, and in close proximity to both ICT and parts manufacturers' research facilities (Goracinova & Wolfe, 2019).

Much of the R&D that is carried out in Canada's auto sector is performed by parts and materials suppliers. While several automakers do have innovation activities in Canada (see Goracinova & Wolfe, 2019), none spend a substantial proportion of their R&D budgets here (Research Infosource Inc., 2019). The tendency to cluster R&D activities in proximity to OEM headquarters, and therefore outside of Canada, is evident among parts supply companies as well. Even the largest Canadian-owned parts firms spend much, if not the majority, of their R&D budgets outside of Canada (Mordue & Sweeney, 2019). Without strong and sustained efforts to support industrial innovation in Canada, this situation is likely to continue.

3.1.2 CASE Vehicles and the Canadian Automotive Industry

CASE vehicles present new opportunities in R&D for the automotive industry in Canada

CASE vehicles present new opportunities in R&D for the automotive industry in Canada. The location of Canada's motor vehicle and parts manufacturing sector in the second-largest ICT region in North America (Ontario) offers a network of expertise valuable to the development of CASE vehicles (GC, 2017; Tanguay, 2018). This includes clusters of expertise in AI, with research in machine learning, deep learning, neural networks, and computer vision (GC, 2019a). Testing facilities in Ontario offer opportunities in the development of CASE vehicle technology that performs safely in all conditions (WSP Global Inc., 2019). For example, the Autonomous Vehicle Innovation Network (AVIN) in Ontario, led by the Ontario Centres of Excellence and supported by the Government of Ontario, has a WinterTech development program intended to "leverage Ontario's unique climate to validate, test and prototype your winter weather automotive technology and mobility solutions" (AVIN, 2020).

Though traditional manufacturing jobs will continue to decline as technology advances and production becomes increasingly automated, new opportunities in transportation and communication services may support growth in the shifting economy worldwide (Gruss & Novta, 2018). The Panel notes there will also be new opportunities within traditional automotive sectors, including shop-floor manufacturing innovation as well as engineering product development in, for example, sub-assembly, alternative powertrains, and R&D. Ford Motor Company announced an investment in Ontario of $1.8 billion to retool their Oakville facility to build new battery electric vehicles and a $148 million investment in their powertrain facility in Windsor (Unifor, 2020). Much automotive R&D today is ICT R&D performed by automotive manufacturers; new vehicle technologies from the ICT sector will transform the production model and likely even the organizational design of the automotive sector (Goracinova & Wolfe, 2019). Nurturing a competitive and innovative automotive ecosystem in Canada will require ongoing support for R&D and collaboration across government, academia, and industry.

The role of the automotive aftermarket in a CASE vehicle future is uncertain

Tension is growing between connected vehicle OEMs and the independent automotive aftermarket parts and services industry regarding access to data generated by telematics (AIA Canada, 2017). Aftermarket service providers have a significant opportunity to take advantage of onboard diagnostics if, for example, connectivity is allowed for more efficient scheduling of maintenance and repair services (i.e., pre-ordering parts, remote diagnosis of wear) (AIA Canada, 2017).

However, such opportunities depend on whether vehicle owners have the legal right to decide who may access the data generated by their vehicles and how those data are used. The Canadian Automotive Service Information Standard (CASIS) is a voluntary agreement between OEMs and the independent aftermarket to allow for the sharing of service information, tools, and training for diagnostics and repairs of vehicles at "commercially reasonable prices" (CASIS, 2009). CASIS addresses access to data from onboard computers, but not connectivity per se (CASIS, 2009). The question of consumers' "right to repair" is ongoing in a number of technology sectors, such as smartphones and farm equipment (Wilkinson, 2020). How legislation in Canada and the United States addresses the issue will undoubtedly have implications for the CASE vehicle industry and the future role of the independent aftermarket.

CASE vehicles also represent a potential loss in demand for repair services due to electrification and automation. Electric vehicles (EVs) have fewer component parts and do not require the same scheduled maintenance as those with internal combustion engines (e.g., no oil changes) (AIA Canada, 2017). Autonomous vehicles are expected to be involved in substantially fewer collisions than human-driven vehicles, ultimately reducing demand for parts manufacturing and repair services (KPMG, 2017a). Moreover, the shared aspect of CASE vehicles points to a shift away from private ownership and towards corporate fleet management, where aftermarket services are delivered company-to-company rather than company-to-consumer (McKinsey, 2018a). Thus, the demand for local, independent garages and shops may fall substantially, though it is difficult to project far into the future.

3.2 The EV Industry

3.2.1 The State of the EV Industry

Vehicle electrification is considered a public good, a necessary response to reduce emissions in the face of climate change, so much so that the demand for electrification is primarily pushed by policy, rather than consumer preference or industry competition (Lutsey *et al.*, 2018; Sperling, 2018). As noted in Chapter 2, the Panel supports the assumption that new vehicle technology (i.e., CASE vehicles) will incorporate electrification in some way (through batteries or fuel cells). Indeed, Norway's high position on the 2019 KPMG *Autonomous Vehicle Readiness Index* is, in large part, due to its high EV uptake (KPMG, 2019). Policy has driven this uptake, with generous tax breaks on EV purchases, as well as free charging stations, toll and parking charge exemptions, and access to bus lanes (Sperling, 2018). Across Europe, 55% of new car sales could be EVs by 2030 (PwC Canada, 2018).

Policy encourages growth in the EV market

Canada is lagging behind some peer countries on the adoption rate of EVs (CEC, 2017); however, the sale of vehicles classified as zero-emissions is rising in Canada. British Columbia and Quebec currently offer some form of financial incentive for EVs; until 2018, such incentives were also available in Ontario (Gov. of ON, 2018). Quebec's Zero Emission Vehicle Standard took effect in 2018, requiring automakers to earn credits through the sale of low- and zero-emission vehicles (Gov. of QC, n.d.). British Columbia offers point-of-sale incentives for zero-emission vehicles, and has recently introduced legislation that would require that all new light-duty vehicles be zero-emission by 2040 (Gov. of BC, 2019).

Purchase subsidies for plug-in electric vehicles increase market shares in modelling scenarios. Axsen and Wolinetz (2018) estimate a market share of 5% to 11% by 2030 for plug-in EVs under current (as of 2018) incentive models, which reaches 14% to 42% when a $6,000-per-vehicle incentive is implemented over 13 years. With the addition of other policy mechanisms that encourage automakers to increase consumer choices for EVs, government expenditures on incentives may be feasibly reduced while still meeting a target 30% market share in 2030 (Axsen & Wolinetz, 2018). Sperling (2018) recommends policy strategies such as education and outreach to increase awareness of EVs, subsidies to encourage the construction and operation of charging stations, and requirements for government fleets to convert to EVs.

Electric buses and commercial trucks are an emerging sector in Canada

Canada is home to a number of electric bus manufacturers, for example, Winnipeg-based New Flyer Industries, the largest bus manufacturer in North America, and Nova Bus, a Volvo-owned company based in Quebec that has supplied battery-electric buses to Montréal and Vancouver fleets (CEC, 2019). Government policy promoting 100% zero-emission bus fleet targets and fuelling infrastructure will help keep and grow the electric bus manufacturing industry in Canada (CEC, 2019). The demand for electric buses in Canadian transit fleets can also draw foreign investment in manufacturing. For example, BYD Company (China) opened an electric bus assembly plant in Newmarket, Ontario in 2019 to supply electric buses to the Toronto Transit Commission (Automotive News, 2019b). Direct federal funding to offset the higher initial purchase price of electric buses, in the same vein as purchase rebates for personal EVs, could provide transit authorities with financial support to ease the transition to zero-emission fleets (Parsons, 2019).

Cost is not the only barrier to electric bus adoption. Transit authorities are concerned about the potential for obsolescence of EV technologies when compared to the 18- to 24-year lifespan of typical transit vehicles, as well as the perception of the technology as immature and unproven (Ferguson *et al.*, 2019). Moreover, the present generation of electric buses have lower operational availability (i.e., running hours per day) compared with diesel or compressed natural gas, requiring larger fleet sizes and more intensive transit system planning. In China, where transit electrification is a national priority, transit authorities lease rather than own electric buses, thus mitigating concerns about obsolescence and immaturity; they have also increased fleet sizes and benefitted from upgrades to the utility grid serving transit infrastructure (Ferguson *et al.*, 2019).

As with transit vehicles, the electrification of commercial vehicle fleets presents opportunities for expansion in Canadian manufacturing and markets. For example, Lion Electric, a Quebec-based zero-emissions vehicle manufacturer, makes all-electric school buses, midi- and minibuses, and, as of 2019, a class-8 urban commercial truck (Hampel, 2019; The Lion Electric Co., n.d.). Dana Incorporated, a U.S. company specializing in the electrification of commercial vehicles, recently acquired Nordresa of Quebec, which manufactures electric drivetrains for commercial vehicles (Dana Incorporated, 2019). However, technological challenges, such as increasing battery density, reducing vehicle weight, and managing battery performance at low temperatures, create uncertainty about when the electrification of larger vehicles, such as long-haul trucks, will be cost competitive with diesel-fuelled alternatives (Sharpe, 2019).

3.2.2 Canada's Role in the Future of EVs

Though Canada is a major sales market[5] for several EV models, such as the Tesla Model S and Model X, and the Chevrolet Bolt and Volt, little to no vehicle or battery cell production for EVs is done in Canada (Lutsey *et al.*, 2018). Tesla battery cells are produced in Japan and Chevrolet batteries in South Korea; both companies' vehicles are assembled in the United States (Lutsey *et al.*, 2018). GM has announced its "first fully-dedicated electric vehicle assembly plant," beginning production in late 2021, in Detroit-Hamtramck, Michigan (GM, 2020). Its proximity to GM facilities in Ontario points to a potential for Canadian research and engineering, as well as advanced manufacturing and automation, to play a role in the supply chain (Waddell, 2020).

Canada is also home to both the raw materials (lithium, graphite, nickel, cobalt, aluminum, and manganese) and highly skilled workforce needed for EV battery production (Hydro-Québec, 2010; KPMG, 2020b; Lu & Drygas, 2020). Additionally, the growing share of EVs in Canada and worldwide will increase demand for safe and efficient battery recycling by an order of magnitude in the next 10 years

5 Lutsey *et al.* (2018) define a major sales market as having had at least 1,000 sales in 2017.

(Lex, 2020). That said, without major investments in EV production from established OEMs (e.g., GM, Toyota) or newcomers (e.g., China-based Johnson Electric and BYD Company), it is unlikely that automotive manufacturing in Canada will be able to take advantage of the growing EV market (Bickis, 2019). In 2020, Ford Motor Company and Unifor ratified a collective agreement that includes substantial investment into EV production at their Oakville and Windsor facilities (Unifor, 2020).

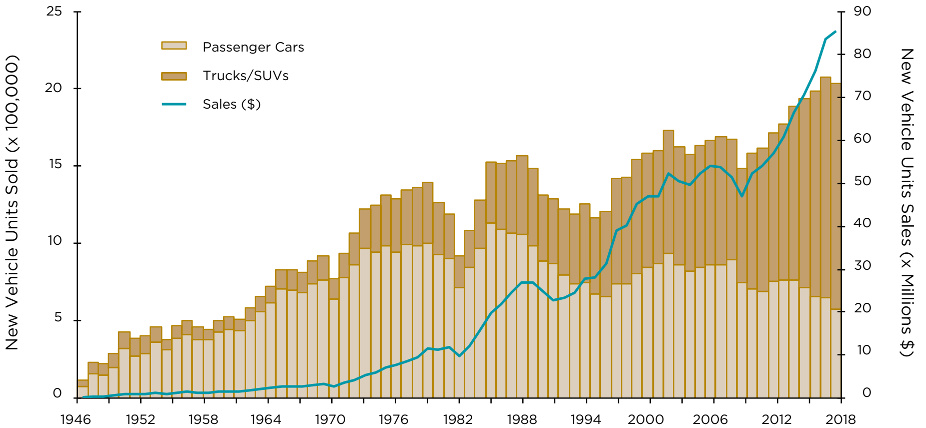
3.3 The Mobility Service Industry

Much speculation on the future of CASE vehicles pivots on whether a mobility service model, where the unit of sale is a ride rather than a car, will disrupt the business model of automotive manufacturers (that is, selling a product to a customer) (e.g., Burns & Shulgan, 2018; Schwartz, 2018; Sperling, 2018). In a mobility service model, the customer base of automotive dealerships, automotive financing companies, and aftermarket parts and repair services could shift away from individual vehicle owners towards companies that manage fleets of CASE vehicles. Substantial opportunities in the software development and communication sectors relate to the operation and use of vehicle fleets, with new opportunity niches in infotainment, transportation management, data analytics, and other applications and services yet unrealized.

3.3.1 The Mobility System in Canada

Most people in Canada rely on personal vehicles for mobility

The proportion of personal vehicle commuters in Canada overall has remained steady in the last 20 years (80.7% in 1996 vs. 79.5% in 2016), with 67% of personal vehicle commuters driving alone (StatCan, 2017c). Outside of commuting and other routine travel (e.g., trips to the grocery store), around 90% of domestic trips made by Canadian residents use rented or privately owned personal vehicles (StatCan, n.d.). While the demand for smaller passenger cars has stagnated, with the number of units sold falling since 2010, the demand for larger vehicles, such as pickup trucks and SUVs, has grown (Figure 3.3). In 2018, the number-one-selling vehicle in Canada was the Ford F-Series pickup truck (Layson, 2019). The managing editor of *AutoTrader.ca* speculated that preferences for larger vehicles reflect a combination of marketing, a desire for features such as four-wheel or all-wheel drive, and an aging population that appreciates the easier transition in and out of a taller vehicle (CBC News, 2018).



Data source: StatCan (2019e)

Figure 3.3 Canadians are Buying Fewer Passenger Cars and More Trucks and SUVs

The total number of passenger cars sold each year in Canada has declined since 2014. Canadians are buying more minivans, vans, SUVs, and pickup trucks, though 2018 was a slow year for all new vehicle purchases. New vehicle sales figures are in current dollars and are not adjusted for inflation.

Some survey evidence suggests that Millennials (people born in the 1980s and 1990s) are more willing than Generation X or Baby Boomers to use car-sharing services, live within walking distance of amenities, and relocate to reduce commutes (Deloitte, 2014). Indeed, 27% of 18- to 34-year-old Canadian respondents to a 2018 Ipsos poll stated that they rely on ride hailing for personal transportation and 48% said they owned or leased a vehicle (compared to 69% of respondents aged 35 to 54 years old and 77% of respondents 55 years and older) (Guy, 2019). However, 51% of respondents aged 18 to 34 years also stated that they were planning to purchase or lease a vehicle in the next 24 months (Guy, 2019). Similar to older generations, Millennial drivers prioritize low cost, convenience, and fun driving experiences over connectivity and eco-friendliness, suggesting limited changes in consumer behaviour across generations (Deloitte, 2014).

The proportion of younger people with a driver's license has fallen in the past decades in a number of Western countries (Sivak & Schoettle, 2012). For example, only 77% of 20- to 24-year-olds had a driver's license in the United States in 2014 compared with 92% in 1983 (Sivak & Schoettle, 2016). However, evidence shows that this reduction in licensing may reflect a delay in acquiring a license rather than rejection of driving altogether (Delbosc, 2016; Rérat, 2018). The 618 respondents (out of 717 surveyed) in the United States between the ages of 18 and 39 who did not have a valid driver's license cited time and money constraints as the most common reasons for not acquiring a license (Schoettle & Sivak, 2013). Recent auto loan data from the United States suggests a continued demand for automobiles among Generation Z (those born in or after 1995), though affordability concerns may be pushing younger buyers towards used vehicles or longer-term loans (Henry, 2019).

Mobility service options are expanding in Canada

Outside of personal vehicle ownership, mobility options may include public transit, taxis, active transportation (e.g., biking, walking), and mobility services (such as car sharing or ride hailing). As of 2018, 20 car-sharing companies in Canada were offering more than 5,000 sharable vehicles, of which over 3,000 were in Vancouver (movmi, 2019). Ride-hailing services (e.g., Uber, Lyft) were available in 22 cities in Canada as of June 2018 (Brail, 2018) and services are expanding. British Columbia's Passenger Transportation Board approved the operation of the province's first ride-hailing service in resort communities outside the Lower Mainland in December 2019 (Orton, 2019). Approvals for ride-hailing services in Vancouver and Victoria followed in early 2020 (CTV Vancouver Island, 2020). Micromobility options are beginning to emerge as well: bike-sharing options are available in numerous cities (see movmi, 2019 for examples), and shared electric scooters recently became available in Canadian cities such as Toronto (Delitala, 2019), Montréal (CBC News, 2019a), Calgary (Smith, 2020), and Edmonton (Romero, 2019). Mobility service options, however, are limited in geographic scope to dense city centres and boutique communities, and are not available in smaller cities, towns, and rural areas, where alternatives to personal vehicle ownership are limited (e.g., a private taxi or community minibus). However, some service options, such as on-demand transit, have been found to be a viable method of increasing access to mobility in times or places where full service transit is not feasible (e.g., the City of Belleville's on-demand transit evening service) (Birring, 2020).

3.3.2 CASE Vehicles and the Future of Shared Mobility

The high initial cost of autonomous vehicles indirectly supports a shared-vehicle model in which multiple people organize to purchase and use a vehicle collectively (Menon *et al.*, 2019). Moreover, CASE vehicle technology will require software and hardware updates to ensure safety and compatibility with new vehicles as development continues, supporting a shared mobility or a subscription-based business model (e.g., leasing, car-share, or ride-hailing services) over one-time vehicle purchases. As Chapter 2 notes, shared mobility service companies are in operation today, where users pay a fee for access to a transportation mode on an as-needed basis; these fees provide for the purchase, parking, cleaning, insurance, and other elements of fleet maintenance (Shaheen *et al.*, 2016). Shared mobility may also be less expensive than personal vehicle ownership for some people; joining a car-sharing program saved U.S. residents US$154 to US$435 per month in transportation expenditures (Shaheen, 2018a).

Shared mobility service companies are investing in autonomous vehicle development

Ride-hailing, shared mobility, and commercial service companies are likely to be some of the first adopters of fully autonomous vehicles (Wadud, 2017; Shaheen, 2018a). Companies such as Uber and Waymo are investing heavily in connected, shared, and automated driving technology (Burns & Shulgan, 2018; SSCTC, 2018); Uber has established its Advanced Technologies Group in Toronto to research and develop such technology (Uber, 2019), and Waymo has launched a self-driving taxi service in Phoenix, Arizona (Boudway & Bloomberg, 2019). Indeed, OEMs have discussed their transition from automobile manufacturers to mobility companies (Shaheen, 2018b). However, with GM's Maven program withdrawing from North American markets, and the withdrawal of Car2Go from Canada, the future of fleet-based car sharing is uncertain (Mathieu, 2020). A peer-to-peer model, where owners offer their vehicle for rent (e.g., Turo), can allow for greater penetration outside of urban areas, avoiding the expense of an up-front fleet investment (Mathieu, 2020). That said, the relative value of different shared mobility service models might well change if CASE vehicles allow ride-hailing services to reduce driver costs and parking expenses and to achieve profitability.

CASE vehicle technology will be used in delivery and freight services

For delivery and freight services, as well as mobility services, the biggest cost savings arising from the emergence of CASE vehicles is in operating expenses. Salary, health care, and insurance costs for drivers are removed or reduced, and vehicle use could be 43% more efficient by removing driver working time restrictions (Godsmark *et al.*, 2015; Ticoll, 2015). Cutean (2017) predicts that truck drivers are less likely to be immediately affected than other driving occupations because demand for professional truckers currently exceeds supply and is projected to continue to exceed supply for several years. Delivery services already using fully autonomous, self-driving vehicles are being tested in limited geographic areas (Lee, 2018). For example, Nuro, in Arizona, is limited to a particular neighbourhood and vehicles cannot go above 25 km/h; however, the vehicle is fully autonomous in those conditions, and does not have space for a human driver (Lee, 2018). Tempe, Arizona, in partnership with the British company Starship Technologies, has small robots that travel on sidewalks delivering pizza and groceries (Fitzgerald, 2020). In Florida, low-speed autonomous shuttles from companies Beep and NAVYA partner with the Jacksonville Transportation Authority to deliver emergency medical supplies (Reiner-Roth, 2020).

3.4 The ICT Industry

In recent years, ICT companies have become more involved in the automotive sector, for example, joining the supply chain for EV producers (Wolfe & Goracinova, 2017). Many ICT companies are developing CASE vehicle technology, with Ontario, Quebec, and British Columbia driving innovation in ICT for the auto sector (EDC, 2017). Therefore, while the automotive industry has almost exclusively been an economic driver in southern Ontario, CASE vehicles could provide economic benefits to communities across Canada, as well as strengthen an ICT sector that accounted for 4.4% of Canada's GDP in 2016 (GtT, 2017).

3.4.1 Integration of the ICT and Automotive Sectors

The dynamics of the ICT sector are different from those of the automotive sector

The automotive industry has long been vertically integrated, with OEMs controlling their supplier networks (Beiker *et al*., 2016) and new entrants. In contrast, the ICT sector is organized more as a network economy where positive feedback reinforces success and companies experience explosive growth as their network of influence expands (Arthur, 1996; Kelly, 1998). Success for technology companies is self-reinforcing as network effects kick in: growth follows an exponential trajectory and new companies find it difficult to enter the market. Thus while a dozen OEMs share the global automotive market, network effects propel tech companies such as Google, Facebook, and Microsoft to enormous market shares (Andriole, 2018).

The integration of Canadian ICT firms into OEM supply chains is therefore likely to be a challenge, especially in the context of strong global competition and uncertainty about the future industry structure. The high cost of development and testing for CASE vehicles has led to new OEM partnerships, such as among Ford, Volvo, and Baidu (Shields, 2018), and between GM and Honda (Welch *et al*., 2018). Value generation in the sector is increasingly tied to ownership of intellectual property (IP) and data, both of which are areas where Canada lags behind comparator countries (EPIP, 2020).

Some experts posit that the continuing development of CASE vehicles will result in increased demand for workers in the ICT sector by up to 15% over the 2030s (Ticoll, 2015), particularly for certain jobs (e.g., software developers, database analysts, and computer engineers) (Cutean, 2017). The Panel notes, however, that there will still be a need for the material components of vehicle manufacturing and assembly (e.g., glass, rubber, and foam), as well as a need to support these established parts of the automotive sector in Canada.

3.4.2 ICT for CASE Vehicles

Canadian companies are active in the development of CASE vehicle technologies

Many successful start-ups in Canada's ICT sector focus on CASE vehicle technologies (Kobus, 2018) and more than 200 companies in Ontario alone are developing technologies (Gov. of ON, 2019c), including sensors, communications equipment, AI, and vehicle operating systems. The development of low-cost, solid-state LIDAR sensors is one of the most potentially lucrative opportunities for the CASE industry. The global market for LIDAR has been predicted to grow from just over US$1 billion in 2017 to over US$5.8 billion in 2024, at a compound annual growth rate of over 24% (Report Ocean, 2019). For example, several companies produce LIDAR sensors for vehicles in Canada, including LeddarTech and Phantom Intelligence in Quebec and Neptec Technologies in Ontario. LeddarTech produced the industry's first 3D solid-state LIDAR system-on-chip (EP&T, 2018), and recently opened an Automotive Centre of Excellence in Toronto (Crane, 2018) to focus on various types of CASE technology including sensors, machine learning, software, and safety standards (Jones, 2018).

The equipment necessary for vehicle-to-everything (V2X) communications includes onboard units and roadside units, as well as mobile network infrastructure (e.g., 5G small-cell transceivers) (McQuinn & Castro, 2018). In Canada, communication equipment companies developing CASE technology include, for example, mmSense, which is developing millimetre wave antennas for vehicles, and Dejero, which is developing connectivity for CASE vehicles, both located in Waterloo, Ontario (Crane, 2018). Developing AI that can reliably match or exceed the performance of human drivers remains perhaps the most difficult technical challenge for SAE Level 4 and 5 driving automation (Section 2.2). Today, Canada has over 650 AI companies, with 5 main commercial centres of expertise in Toronto, Vancouver, Montréal, Kitchener-Waterloo, and Edmonton (PPF, 2018). Uber recently set up its Advanced Technologies Group in Toronto devoted to CASE technology, with a particular focus on AI (Uber, 2019). University of Toronto professors lead Samsung and Nvidia AI research labs (Sorensen, 2018). In 2017, the federal government created the *Pan-Canadian Artificial Intelligence Strategy* to capitalize on Canada's basic research strength in the field (PPF, 2018). However, Canada faces challenges related to commercialization and developing and retaining talent in the AI industry (PPF, 2018). It also continues to fall behind other countries (such as the United States and China) in AI patents (IT World Canada Team, 2018).

Companies developing operating systems (OS) for CASE vehicles include existing OEMs and auto suppliers, as well as tech companies such as BlackBerry QNX, Google, and Apple. BlackBerry QNX, the largest ICT company in Canada's CASE ecosystem, produces an operating system used in a variety of devices, including mobile phones and vehicles. In 2018, the QNX operating system was used in approximately 120 million vehicles around the world, up from 60 million in 2015 (Crane, 2018). In addition, BlackBerry QNX is involved in developing other CASE software components, including telematics, infotainment, and ADAS (QNX, n.d.), and recently opened its Innovation Centre for Connected and Autonomous Vehicles in Ottawa (Crane, 2018).

The demand for infotainment services will increase with CASE vehicles

The removal of drivers has created speculation about the growth in infotainment services, including hardware, software, and content development. Experts suggest that infotainment may increase demand for CASE vehicles through a synergistic effect wherein each technology increases demand for the other (Anderson *et al.*, 2016). The growth in infotainment services is widely anticipated as the proportion of drivers who must concentrate on the road decreases compared with passengers who are looking to be entertained. Estimates of infotainment market value vary. A 2020 report estimated its value at approximately US$24.3 billion in 2019, and projected it to reach US$54.8 billion by 2027, at a compound annual growth rate of 10.7% (MarketsandMarkets, 2020). Another 2017 report estimated a value of around US$28 billion in 2016 and US$36 billion in 2021 (FutureSource, 2017). A 2019 report estimated a market value of approximately US$18.8 billion in 2018 and US$53.3 billion in 2026, at a compound annual growth rate of 13.9% (Reports and Data, 2019).

3.5 The Labour Market

The increasing development and use of automation and AI will necessitate skills training and education for a large portion of the Canadian workforce

The labour market impact of CASE vehicles will likely be concentrated in the following sectors: manufacturing (NAICS 31–33), transportation and warehousing (NAICS 48–49), and information and cultural industries (NAICS 51) (Cutean, 2017). It is likely that CASE vehicles will shift a significant proportion of autoworker jobs away from materials, mechanical, and manufacturing fields, and towards computer hardware development, software development, and ICT services (Gingras, 2016). Many manufacturing jobs will be lost to automation, necessitating an upskilling of workers for jobs in software development and transportation engineering and planning as well as support for workers for whom such upskilling is not feasible. ICT workers in occupations that are mostly likely to be impacted by CASE vehicles make up approximately 5% of the Canadian workforce (Cutean, 2017). However, other industries are also competing for skilled ICT workers, and there is concern that the future supply of these workers may not meet the continuously growing demand (PPF, 2018). Tradespeople, such as mechanics, will require training in the skillsets necessary to service CASE vehicles. Investment in education, skills training, and continuous learning programs relevant to CASE vehicles (e.g., computer science, electrical engineering, ICT) will help ensure that Canada's workforce remains an asset to companies worldwide, while also helping transition the existing workforce to new opportunities as they arise.

Drivers, notably truck, taxi, ride-hailing, and delivery drivers, are likely to be the group most impacted by CASE vehicle technology as occupations involving human drivers will be increasingly phased out (Cutean, 2017). The emergence of ride-hailing services such as Uber and Lyft have already dramatically affected the nature of work in this sector, as well as the demographics of the workforce (Ticoll, 2015; Cutean, 2017). The replacement of human drivers with autonomous vehicles could lead to a 50 to 90% reduction in ride-hailing driving jobs (Ticoll, 2015). However, such impacts are unlikely to occur in the next 10 years, as the development of CASE vehicle technology is ongoing, and such technology is not widely available for commercial use in Canada. Moreover, as there is an expected shortage of 34,000 truck drivers by 2024 (Cutean, 2017), the impact on the trucking industry may be limited as well, as the demand for truck drivers will likely exceed the supply in Canada in the next decade.

3.6 Summary

CASE vehicles represent both standard and disruptive technologies to the motor vehicle and parts manufacturing industry. While vehicles will still require some component parts from established suppliers (e.g., wheels, windshields, and chassis), new players (ICT companies) will enter the automotive supply chain with the integration of the software and hardware necessary for connectivity and automated driving. ICT companies operate in the network economy, with success often linked to first mover advantages (i.e., being the first, and therefore only, available technology for some time) and standardization more so than improvements to productivity or cost. That is, a company that becomes the major supplier of CASE operating systems, sensor technology, or AI can corner the market through saturation rather than necessarily offering the best, cheapest, or most efficient product. The race to become the standard in CASE vehicle technology is happening now on a global scale, and it is not yet clear whether many or few industry players will occupy the CASE vehicle market. CASE vehicles create opportunities for R&D in the automotive and ICT sectors, though it is unclear whether Canada will be able to attract and maintain commitments from both international and domestic firms without sustained, coordinated, and supportive public policy.

4

Insurance and Liability

Chapter Findings

- The development of CASE vehicle technology will outpace product liability and insurance laws and regulations in the next 10 years. Canada's existing system of tort law may be capable of dealing with the challenges posed by vehicles at SAE Levels 3 and lower, but new or amended legislation will likely be required to address the novel liability issues that will arise at Levels 4 and 5.
- CASE vehicles may cause the consolidation of insurance companies. With the advantage of direct access to CASE vehicle data, new, non-traditional competitors may enter and disrupt the industry.
- CASE vehicles are likely to lower demand for personal auto insurance due to reduced personal vehicle ownership, and increase demand for commercial auto insurance as ride hailing and car sharing become more common. Insurance companies may also offer a range of new products and services tailored to CASE vehicles.
- Usage-based insurance will likely increase as telematics are used to distinguish driver liability from vehicle liability. Drivers may face new liability risks by failing to follow appropriate protocols for a given level of automation or for failure to update vehicle software.

Auto insurance in Canada is provided by about 108 private property and casualty (P&C) companies (IBC, 2018b) and by provincial government-owned insurers in British Columbia, Saskatchewan, Manitoba, and Quebec. The largest P&C insurers dominate the insurance market, with the top six representing over 50% of the industry, as measured by direct written premiums (Deloitte, 2018b). Auto insurance is the largest business line for P&C insurers, accounting for approximately half of all premium revenues (IIC, 2016). In 2017, auto insurers in Canada collected $20.3 billion in net written premiums,[6] representing nearly 43% of all net written premiums in the insurance industry (IBC, 2018b). Auto insurers paid out $14.9 billion in net claims in 2017, down from $15.2 billion in 2016, but up by nearly 28% since 2007 (IBC, 2018b). Auto insurance claims costs have increased significantly over the past few decades (IIC, 2016).

6 Net written premiums are "direct written premium amounts (the total amount of premiums that a P&C insurance company receives in one year) plus reinsurance written premium amounts minus reinsurance ceded premium amounts" (Deloitte, 2018b). The numbers reported do not include government-provided auto insurance.

Adjusted for inflation, the cost of auto insurance claims in Canada has doubled over the past 30 years (IIC, 2016).

Auto insurance is provincially/territorially regulated in Canada, and coverage is mandatory in all provinces and territories. Mandatory coverage includes accident benefits regardless of who caused a collision, i.e., "no-fault" insurance (except in Newfoundland and Labrador); third-party liability (i.e., coverage for property damage and compensation for injuries or deaths that are the fault of the driver); and uninsured auto (covering injury caused by an uninsured or unknown driver) (IBC, 2018b). Provincial and territorial legislation dictates many aspects of the insurance industry, including the claims process, complaint management, and insurance rates, which limits the products and prices that insurance operators can offer their customers (IBC, 2018b). This also means that auto insurance rates and coverages vary among provinces and territories, and any changes to the way insurance is provided in Canada will require changes to the legislation of each province and territory. The impact on the insurance industry of the introduction of CASE vehicles will vary correspondingly by province or territory.

4.1 CASE vehicles and the Determination of Liability and Fault

The question of liability in the case of CASE vehicle collisions is of great importance not only to insurers, but also to CASE vehicle developers and manufacturers, software providers, and infrastructure managers, as well as shared mobility service providers and the end users of CASE vehicles: the people who risk being injured in a collision (Smith, 2017). Different challenges with respect to liability and fault determination will arise with different likely future stages of CASE vehicle deployment: (i) SAE Level 2 and 3 vehicles sharing the road with conventional vehicles, (ii) Level 4 and 5 vehicles sharing the road with conventional vehicles, and (iii) Level 4 and 5 vehicles dominating the roads (Deloitte, 2018b).

Distinguishing human driver liability from technology liability will be increasingly challenging with SAE Level 2 and 3 vehicles

In the first stage, challenges will relate to distinguishing driver liability from vehicle liability, i.e., establishing whether a collision was caused by a human or by the automated components of a vehicle (due to a malfunction or a technical error) (IIC, 2016; Munich RE, 2016; Deloitte, 2018b). Drivers may face liability risks by failing to follow appropriate protocols for a given level of automation (e.g., failing to pay attention to the road or take over in a timely manner in SAE Level 2 and 3 vehicles) or failing to properly maintain the vehicle (BLG, 2016). This will be a particularly challenging and complex stage of CASE vehicle deployment for the determination of liability, as it will involve multiple actors and stakeholders (e.g., drivers, automakers, mobility service providers, technology and software companies) and deal with issues related to driver attention and reengagement (IIC, 2016; Deloitte, 2018b). Analysis of telematics data may allow for the development of split risk profiles, where driving performance is assessed and assigned to the human driver or automated driving system (Ryan *et al.*, 2018). It is not yet clear how liability and fault (and therefore costs) will be shared in situations where both driver error and vehicle technology contribute to a collision (IIC, 2016).

As the level of automation increases, so too will the liability exposure of vehicle manufacturers and technology providers

In later deployment stages, liability will increasingly shift from the driver to technology providers, potentially simplifying fault determination and liability to some degree (IIC, 2016; Deloitte, 2018b). In general, the greater the level of automation, the greater the liability exposure of vehicle manufacturers and technology providers (KPMG, 2015; Munich RE, 2016). During this shift, demand for new insurance products is likely to increase dramatically (KPMG, 2015; Deloitte, 2018b; IBC, 2018a). The European Parliamentary Research Service has identified four main sources of liability-related risk that are unique to CASE vehicles: (i) software failure, (ii) network failure, (iii) hacking and cyberattacks, and (iv) decision-making algorithms (Evas, 2018). In addition, it is possible that CASE vehicle manufacturers could be held liable for failing to sufficiently educate drivers on the safe operation and limitations of automated driving systems, for misrepresenting the capabilities of the systems, or for failing to account for certain aspects of human-machine interaction (Smart *et al.*, 2017; Smith, 2017). Liability could also shift to road authorities, both those responsible for approving CASE vehicles for use on public roads and those responsible for maintenance and upkeep of public roads. For example, if the road markings that CASE vehicles use to centre themselves in a lane are not clearly visible due to lack of maintenance, that could open the responsible road authorities to liability (Bennett, 2019; Vellinga, 2019). While details vary by province, in some cases road authorities in Canada (including municipalities and provinces) may be liable if they fail to adequately maintain their roads (Groulx & Casey, 2003; Howard-Duke, 2013).

Questions have also arisen around the standards for negligence as applied to CASE vehicles. If CASE vehicles purport to be safer than human drivers, then they may be held to higher standards with respect to their capacity to avoid dangerous events. Situations could arise in which a CASE vehicle may be found to have been negligent in avoiding a collision, while a human driver in the same situation would not (Smith, 2017).

Box 4.1 Who Might Be Liable for CASE Vehicle Collisions?

- **Automakers and component manufacturers** face liability related to component failure. While such entities are currently responsible for only about 2% of collisions, this could climb to 80 to 100% with the introduction of CASE vehicles (Deloitte, 2018b). Many automakers have already publicly stated that they will accept liability for collisions caused by their vehicles when in autonomous mode (IIC, 2016; Deloitte, 2018b)
- **Software developers** face liability related to software bugs or glitches, as well as cybersecurity vulnerabilities. Liability for these entities will likely increase as vehicles become more autonomous (i.e., SAE Levels 4 and 5) (Deloitte, 2018b).
- **Owners and operators of autonomous vehicles** face liability related to collisions that occur when a vehicle is under their direct manual control. They are also likely to face liability in situations where they modify the hardware or software of their vehicle or fail to properly maintain it (BLG, 2016; Deloitte, 2018b).
- **Mobility service providers** (such as Uber and Lyft) will face liability similar to that of other owners and operators of autonomous vehicles (Deloitte, 2018b).
- **Infrastructure developers and operators** that are responsible for V2I-enabled infrastructure may be liable for collisions caused by a failure to communicate properly with vehicles, including incorrect messages and malfunctions. They may require new, specialized insurance products and services, as well as new standards and regulation for liability (Deloitte, 2018b).
- **Third-party service providers** such as GPS or weather services could potentially be held liable for damages or injuries resulting from their use, depending on whether such entities are found to have a "duty of care" (BLG, 2016).

The increased prevalence of CASE vehicles will require revisions and updates to laws and regulations on liability and fault determination in auto collisions (KPMG, 2015; BLG, 2016; Deloitte, 2018b; IBC, 2018a). In Ontario, autonomous vehicles allowed on roads for use in pilot projects must be insured for a minimum of $5 million in liability coverage for injury or death to persons, property damage, or loss; this rises to $8 million for vehicles with a seating capacity of eight or more (Gov. of ON, 2019a). Quebec requires autonomous vehicles to hold a minimum liability coverage for property damage of $1 million as well as the standard no-fault coverage required under the *Automobile Insurance Act* (Gov. of QC, 2018).

How current liability law will apply to future vehicles is largely unknown (Munich RE, 2016). Unique issues may arise because many of Canada's jurisdictions are common law, and liability is decided by case law rather than statute (BLG, 2016). However, the novelty of the issues raised by CASE vehicles may mean there is no clear legal precedent to draw upon (IIC, 2016).

Insurance options for CASE vehicles include product liability, single policy, and no-fault

The shift in liability from human drivers to CASE vehicle technology could mean that individuals injured in motor vehicle collisions involving CASE vehicles have to seek compensation through product liability litigation (Smith, 2017), which is typically far lengthier (up to several years longer) and more complex than traditional auto liability litigation (IBC, 2018a). This shift may also require injured people to engage directly in expensive legal actions against large, well-resourced companies such as vehicle or technology manufacturers (Deloitte, 2018b; IBC, 2018a). This type of product liability coverage is often used for other types of highly autonomous vehicles, such as aircraft, trains, and ships (IIC, 2016), and some have argued that it is likely to be compatible with future CASE vehicles (e.g., Smith, 2017). However, several challenges are associated with product liability in the context of CASE vehicles. For instance, insurance rates for these other types of highly autonomous vehicles are typically not subject to regulatory approval (IIC, 2016). Product liability is also mainly governed by common law, not statute (BLG, 2016), making it more difficult to apply in the context of automobile collisions due to lack of case history. Furthermore, the development of new technology will likely outpace the development of product liability law, and therefore offer little guidance for novel situations (BLG, 2016). For example, the software algorithms controlling CASE vehicles may not be considered "products" for the purposes of liability law (Smith, 2017). In addition, while product liability may be applicable to privately owned autonomous vehicles, CASE vehicles may present additional complications that may not be covered by traditional product liability frameworks (Calo, 2019). Finally, product liability could distort the economics of autonomous vs. conventional vehicles: if manufacturers have greater liability exposure with autonomous vehicles than with conventional vehicles, it is likely that the price of autonomous vehicles will be correspondingly higher (Smith, 2017).

Suggested alternatives to the product liability approach include the single policy approach and the no-fault approach. Under the former, recommended by the

Insurance Bureau of Canada and implemented in the United Kingdom in 2018 (Gov. of UK, 2018), the "automated vehicle's insurer would compensate injured people if the automated vehicle caused a collision, regardless of whether the human operator or automated technology was in control" (IBC, 2018a). This would align the tort process for CASE vehicle-related claims with that for traditional vehicles, and would allow injured persons to still pursue direct claims against a vehicle manufacturer or software provider (IBC, 2018a).

The no-fault approach does not depend on determining who (or what) is at fault in the collision (Anderson *et al.*, 2016; IBC, 2018a). Some sources have argued that no-fault insurance for CASE vehicles may be incompatible with Canada's current mixed no-fault and tort policies, and would require major policy changes at the provincial and territorial level (IBC, 2018a); however, others suggest that it could continue to be used in the case of CASE vehicles without modification (BLG, 2016). In addition, no-fault insurance may be more vulnerable to fraud and have higher costs (IBC, 2018a). No-fault insurance policies often contain exceptions for collisions that cause serious harm (BLG, 2016), which would have to be addressed in some other way. Canada's existing system of tort law is likely capable of dealing with the challenges posed by vehicles at SAE Levels 3 and lower, with new legislation likely required in order to address novel liability issues that arise with vehicles at Levels 4 and 5 (BLG, 2016).

4.2 Impacts of CASE Vehicles on Auto Insurance Demand and Costs

CASE vehicles will likely decrease the number and frequency of claims due to the increased safety from automated driving systems (Matley *et al.*, 2016). They may also lower the demand for personal auto insurance as more people use shared mobility services, and potentially reduce the total number of insured vehicles due to fewer overall vehicles on the road (IIC, 2016; Matley *et al.*, 2016; Deloitte, 2018b).

According to some estimates, the impact of CASE vehicles on the auto insurance industry is likely to be relatively small until the mid-2020s, with significant disruption of the industry in the following decades (IIC, 2016). The impact on insurance premiums has been forecast to become significant by 2026, and could represent a $25 billion loss for insurers in the United States over the next 15 years (Cusano & Costonis, 2017). Matley *et al.* (2016) predict a 30% decrease in total auto insurance premium needs resulting from the shift towards CASE vehicles. KPMG (2015) estimates that CASE vehicles could shrink the total auto insurance market by 40% by 2040, with demand for personal auto insurance predicted to decrease by 60%, but demand for commercial auto insurance predicted to increase. By 2040, commercial auto insurance is predicted to rise to roughly 28% of total payouts, up from 13% in 2013 (KPMG, 2015), due to increased demand from ride-hailing and car-sharing companies, as well as the shift in liability from the driver to CASE vehicle automakers and technology providers. In a survey of members of the Insurance Institute of Canada, 73% agreed that the emergence of CASE vehicles will be difficult for the insurance industry and 46% agreed that the industry is not sufficiently prepared for the anticipated decrease in the frequency and severity of auto collisions (IIC, 2016).

Insurance premiums may increase in the next ten years, and decrease in the long term

While automated driving may ultimately result in lower insurance premiums over the long term (20+ years), some experts predict that premiums will increase in the medium term (10 to 20 years). The cost per claim may increase due to the high costs of replacing damaged technology components such as sensors and computer systems (KPMG, 2015; IIC, 2016; Matley *et al.*, 2016; Munich RE, 2016; Deloitte, 2018b). A Deloitte (2017) study found that replacing damaged CASE vehicle components such as sensors was five times more expensive than replacing conventional parts, and a KPMG (2017a) study estimates that CASE vehicle technology components will cause repair costs to increase by 10% by 2030 and by 20% by 2040. Moreover, sensors are often located on sections of the vehicle that are susceptible to damage in auto collisions, such as the front and rear bumpers (IIC, 2016; Deloitte, 2018b). Reduced collision rates could help offset the higher cost per claim; however, an estimated 25% to 50% of all vehicles on the road would need forward-collision prevention systems for this to occur (Deloitte, 2018b).

Insurance premiums may also rise in the medium term because of increased risks of collisions associated with SAE Level 2 and 3 automation due to technical glitches with new technology, drivers inappropriately over-relying on automated driving systems, drivers failing to pay sufficient attention to the road in shared driving situations, and the mix of autonomous and conventional vehicles on the roads (Deloitte, 2018b).

Over the long term, auto insurance premiums are likely to decrease as CASE vehicles become more common and the frequency of collisions is reduced. This will be a positive benefit to consumers by reducing the costs of vehicle ownership. However, insurance companies will have to prepare for a decline in premium revenues, and adjust their business models accordingly (KPMG, 2015; IIC, 2016; Deloitte, 2018b). The long-term decrease in premium revenue could leave very little margin for error in underwriting for the industry. The U.S. insurance industry has not generated a profit on commercial auto insurance underwriting since 2010, or on private auto insurance underwriting since 2008 (KPMG, 2015). The emergence of CASE vehicles is likely to disrupt the industry even further, putting considerable strain on the profit margins of insurers, and likely causing "significant turmoil" (KPMG, 2015).

CASE vehicles will likely reduce the number of auto insurance claims in the long term

Several sources predict a significant reduction — potentially by as much as 80% — in the number and frequency of auto insurance claims by 2040 (KPMG, 2015; IIC, 2016; Matley *et al.*, 2016). Several factors are expected to contribute to this reduction, including a decrease in the demand for personal auto insurance resulting from a reduction in personal vehicle ownership, as well as a reduction in collisions due to the increased safety of CASE vehicles. Indeed, currently available vehicles with automated front-collision protection systems reduce the frequency of insurance claims by 7 to 15% (KPMG, 2015). The decrease in claims is expected to reflect the rate of CASE vehicle adoption in a geographical area (Matley *et al.*, 2016). Based on an analysis by KPMG (2015), the Insurance Institute of Canada (2016) predicts a 10% reduction in the average cost per vehicle of providing auto insurance by 2025, due to the combined impact of fewer insurance claims and a higher average cost per claim.

Liability and decision-making algorithms for CASE vehicles will influence premium rates

One of the most pressing ethical considerations for autonomous vehicles concerns pre-programmed decision making that leads to collisions (e.g., swerving into a wall to avoid running over a pedestrian). Insurance companies will likely use the algorithms that determine a vehicle's actions as a basis for determining liability risks (Deloitte, 2018b). For example, a CASE vehicle programmed to protect its occupants over pedestrians may have different risk profiles and liability exposure than one programmed to do the opposite. Thus, different insurance premium rates could be set for different types of algorithms with different liability implications. Broad societal conversations that include regulators, legislators, lawyers, ethicists, the public, and others will be required in order to determine the best course(s) of action for autonomous vehicles to take in ethically challenging driving situations (i.e., "trolley problem" scenarios[7]). As a result, it is likely important for the insurance industry to be involved as a relevant stakeholder in discussions about CASE vehicle programming.

7 Traditional "trolley problem" scenarios have been disputed as useful models for autonomous vehicle programming or policy as they present simple binary choices that are intended to clarify ethical intuitions rather than provide a practical guide to action (Freitas *et al.*, 2020). The term is used here to denote situations wherein autonomous vehicle decision-making algorithms are faced with dangerous, ethically complex scenarios where harm may be unavoidable.

4.3 New Business Models for the Auto Insurance Industry

CASE vehicles will affect the business model of the insurance industry, resulting in the emergence of new insurance providers, new products, and new regulatory and governance systems. CASE vehicles may present a threat to the business model of insurers that mainly offer personal auto insurance, as CASE vehicle technology will have the greatest impact on these companies (KPMG, 2015). Demand for traditional auto insurance products and services (such as personal auto insurance) will likely decrease, though demand for insurance in general may increase as companies look to insure fleets of vehicles (Deloitte, 2018b). Insurance companies may also offer a range of new products and services tailored to CASE vehicles (Box 4.2). In addition, demand for insurance covering physical damage to the vehicle or its components may increase due to the higher cost of repairing or replacing CASE vehicle technology such as sensors and computer systems (KPMG, 2015; IBC, 2018a).

Box 4.2 Types of New Insurance Products and Services for CASE Vehicles

- **Autonomous product liability insurance** for manufacturers and operators that covers hardware and software malfunctions. Experts predict that the product liability insurance market will dramatically increase to roughly the size of the current commercial auto insurance market (IIC, 2016), as will demand for product liability insurance (Cusano & Costonis, 2017).
- **Cybersecurity insurance products** for CASE vehicle hardware and software providers that covers hacking, cybertheft, ransomware, and misuse of customer information. These products may be particularly attractive to companies that operate large fleets (Cusano & Costonis, 2017).
- **Infrastructure insurance** for V2I-enabled infrastructure and cloud server systems that covers malfunction or incorrect signals (Cusano & Costonis, 2017).
- **Fleet operation liability insurance** for shared mobility providers such as Uber and Lyft (Deloitte, 2018b).
- **Passenger insurance** that covers an individual riding in a CASE vehicle (Gill, 2018). Such insurance could cover damage to the vehicle caused by the passenger or against loss or damage of personal property while in the vehicle, or provide an additional source of insurance in the case of injury.

CASE vehicles may lead to a consolidation of insurance companies across the industry, as well as new, non-traditional competitors and partnerships

Some experts expect a consolidation of insurance companies across the industry (KPMG, 2015; Deloitte, 2018b), especially as smaller insurers may be unable to offer insurance to companies operating large fleets (such as Uber and Lyft) and do not have the technical expertise to deal with CASE vehicle data. Resource rich insurance companies will be better placed to insure larger commercial customers, due to their significant cash reserves (Deloitte, 2018b). The increased revenue from such customers may help offset the expected decrease in revenues from personal auto insurance for these insurers (Deloitte, 2018b). Some analyses suggest that insurers may be tempted to drop premium prices below the profitability threshold to remain competitive and capture a greater market share; this action could result in instability for the entire industry (KPMG, 2015).

New, non-traditional competitors, including automakers, tech companies, and ride-hailing and car-sharing companies, could enter and disrupt the insurance industry (Deloitte, 2018b). These companies may provide their own insurance products and services to gain market share. Indeed, self-insurance could become the dominant model for large CASE vehicle fleet operators (Matley *et al.*, 2016). They are also likely to have an advantage to the extent that, unlike traditional insurers, they have direct access to CASE vehicle data (Deloitte, 2018b). It is not yet clear how to incentivize such companies to share data with traditional insurance companies (Deloitte, 2018b).

Insurers may partner with stakeholders in other sectors (such as ICT or auto manufacturing in the private sector, or governments in the public sector) to co-develop insurance products and services (Matley *et al.*, 2016). Such partnerships are already occurring. In Canada, Tesla has developed partnerships with Aviva to offer unique insurance products based on its autopilot feature (Tesla, 2019), and with other companies in the United States and Asia (Muoio, 2017). As well, insurers may partner with mobility service providers (such as Uber and Lyft) or automakers to offer "bundled" products consisting of monthly or yearly subscriptions to vehicles, with insurance included (Deloitte, 2018b).

CASE vehicles will require different types of insurance products and services

There is likely to be an increase in usage-based insurance (UBI), in which driver behaviour is tracked via telematics systems, often in real time, to provide individualized premium pricing (NAIC, 2020). First introduced in Canada in 2013, UBI models may allow insurers to more accurately assess individual risk levels and set premiums accordingly, which could increase affordability for the consumer (InsuranceHotline.com, 2019). UBI models may also incentivize consumers to reduce the number of kilometres driven and adopt safer driving behaviours, as these are directly linked to premium cost (Deloitte, 2018b; NAIC, 2020). This change could improve safety, reduce premium costs, and potentially even have positive environmental effects (Deloitte, 2018b).

The current regulatory framework for insurance may be unsuited to CASE vehicles, with potential challenges around the development of new insurance products (Deloitte, 2018b). Partnerships between insurers and automakers and the embedding of insurance coverage in bundled products may give rise to issues regarding consumer choice, transparency, and anti-competitive behaviour (Deloitte, 2018b). In addition, regulators may require new entrants to the insurance industry (including automakers and mobility providers that elect to self-insure their vehicles) to purchase some types of catastrophic coverage from established insurers (Matley *et al*., 2016).

Different job skills will be required in the future auto insurance industry

The P&C insurance industry employed approximately 126,200 people in Canada in 2017 (IBC, 2018b). Some of these jobs may be at risk over the coming decades if CASE vehicles cause the total auto insurance market to shrink. Regardless, as new technology enters the automotive market, insurance underwriters will need technological expertise in order to assess the unique risks associated with new hardware and software components, and the risk profiles associated with different types and levels of automation (Munich RE, 2016; Deloitte, 2018b). They will also need strong skills in data analytics as assessing risk becomes more dependent on the analysis of telematics data. The demand for data analytics will also increase the use of AI in the insurance industry, which is expected to grow dramatically in the near future (Deloitte, 2018c).

4.4 Implications of CASE Vehicle Data for Insurance

Insurers are eager for access to vehicle telematics data, which could allow them to more accurately and efficiently assess risk, process claims, and detect fraud (IIC, 2016; Deloitte, 2018b; IBC, 2018a). However, a range of issues have come up related to data access, ownership, and use in the context of CASE vehicle data in the auto insurance industry (IIC, 2016; Smith, 2017; Deloitte, 2018b). Issues around access to CASE vehicle data in legal disputes about liability may ultimately need to be resolved by the courts. Privacy concerns have also arisen related to the use of CASE vehicle data in the insurance industry (Lawson *et al*., 2015; Deloitte, 2018b), as the data collected by insurers may reveal not only an individual's driving behaviour, but also their travel patterns, habits, destinations, and other potentially revealing information (Zhou *et al*., 2019) (Chapter 5).

CASE vehicle data will be required by insurers to assess risk

Insurers may need access to large datasets containing various types of data to quantify the risk of collisions and corresponding premium prices for CASE vehicles (Box 4.3). One significant challenge is that the actuarial approach to insurance rates uses historical loss data to anticipate future costs (IIC, 2016). Typically, a large insurance company might rely on a dataset of 100 to 150 billion miles driven to quantify risk (Munich RE, 2016). Initially, however, there will be very little historical CASE vehicle data to rely on when quantifying risk for these vehicle types. As a result, insurance companies may decide to share and aggregate CASE vehicle data to provide more robust analyses and produce meaningful insights (Munich RE, 2016). The Insurance Bureau of Canada (2018a) has recommended establishing data-sharing arrangements between vehicle manufactures, vehicle owners, and insurers.

The development of "data trusts," as set out in the federal government's proposal for modernizing Canada's privacy laws, could facilitate such data pooling (ISED, 2019b). This proposal involves "trusted third parties managing access by organizations to sensitive databanks for research and development purposes, while protecting privacy and ensuring that organizations use data appropriately" (ISED, 2019b). The Government of Canada also notes that this approach has been used in the United Kingdom and Australia, as well as in the EU under the *General Data Protection Regulation* (GDPR) (ISED, 2019b).

Box 4.3 Types of CASE Vehicle Data Used by Auto Insurers to Assess Risk

- **Kilometres driven:** The more time a driver or vehicle is on the road, the higher the risk of a collision. With CASE vehicles, insurers may distinguish between kilometres driven autonomously vs. kilometres driven by a human driver in order to more accurately assess risks and premiums.
- **Location:** Vehicle location may indicate risk of collisions. Time spent on mapped vs. unmapped roads may also be a factor. However, location data may be considered sensitive information, and access may be tightly regulated or even blocked.
- **Driver identification:** If autonomous vehicles automatically identify the driver of the vehicle, insurers may use this information to assess levels of risk.
- **Time of day:** The time of day that a vehicle or driver most often travels may affect their risk rating, due to traffic conditions or other factors associated with that time of day.
- **Weather data:** Weather data may be useful for determining fault in collisions, which could help with claim processing.

Munich RE (2016), Deloitte (2018b)

Claims processing may be accelerated with access to CASE vehicle data

Sensor and telematics data could be collected or monitored remotely to analyze CASE vehicle activity and performance leading up to a collision (Deloitte, 2018b). Insurers may consider telematics data to be more reliable than information obtained directly from drivers (Munich RE, 2016; Deloitte, 2018b). These data could include the location and time of a collision; whether the vehicle was in automated driving mode, for how long, and what kinds of ADAS were engaged; the timing of any driver interventions (e.g., steering, braking, accelerating); any warnings or notifications to the driver; and whether the driver's seat was occupied and seatbelt engaged (IBC, 2018a). Data obtained from nearby vehicles and roadside infrastructure could further help insurers analyze collision events. All of these data may help insurers to more accurately identify reasons for a collision and determine fault, resulting in more efficient claims resolution (Matley *et al.*, 2016). These same data may also be useful to law enforcement for determining fault in auto collisions (Deloitte, 2018b). All of these types of data would be necessary in implementing a single-policy approach to liability (IBC, 2018a).

However, challenges also exist around the collection and use of autonomous vehicle data for insurance purposes (Munich RE, 2016). Some vehicle owners may be reluctant to share this information with insurance companies, and it is not clear how courts might resolve disputes between different stakeholders about access to CASE vehicle data (IIC, 2016).

Telematics and sensor data can help insurers detect fraudulent claims

Insurers will likely want access to telematics and sensor data in order to detect fraudulent claims more effectively. Between 13% and 17% of auto insurance claims are fraudulent (IRC, 2015), and fraudulent auto insurance claims in Canada are estimated to cost $1.6 billion annually, though some insurers estimate the annual cost at $2 billion (Nadarajah, 2018). Up to 80% of an insurance company's costs can be claims (Deloitte, 2018b). Therefore, if access to CASE vehicle data reduces the number of fraudulent claims, that may partially offset the expected decline in revenues caused by the introduction of CASE vehicles (Deloitte, 2018b). Matley *et al.* (2016) estimate that a 10% reduction in fraudulent claims could result in annual savings of up to US$800 million across the entire U.S. insurance industry.

4.5 Summary

As vehicle technology moves towards greater automation, liability and fault in automobile collisions are shifting from drivers to manufacturers, owners, and operators. How this shift happens in insurance regulations and tort law remains to be seen, though various regulatory changes are being considered and implemented around the world. For example, product liability claims for people injured or killed in CASE vehicle collisions will likely prove lengthy, expensive, and difficult to pursue in the court system; single policy or no-fault insurance could provide more immediate funds for individuals seeking compensation to cover health care costs and lost wages. Proactive changes to regulations to anticipate CASE vehicles can help ensure universal and timely insurance coverage.

Opportunities for new insurance products and business models may compensate for a predicted reduction in the number of collisions over time, though the industry will likely lose smaller insurance companies and consolidate around a few larger players that provide products to fleet operators and managers. Similarly, the number of jobs in the auto insurance industry will likely decline, and new skills and expertise will also be required to assess risk with new CASE vehicle technologies.

5

Data, Privacy, and Cybersecurity

Chapter Findings

- CASE vehicles generate enormous volumes and new types of data. The use of this data may pose risks to personal privacy and vehicle cybersecurity, but could also provide benefits such as increased safety, efficiency, and accessibility for the public sector, as well as numerous business opportunities for automakers, MaaS providers, auto insurers, and others in the private sector.
- Data-sharing practices for CASE vehicles are complex and subject to ongoing development. Various organizations may have access to data collected by CASE vehicles, with competing claims of ownership to the same data and no clear way to resolve these disputes. Data may be stored outside of Canada and accessed or used by foreign companies and governments, challenging cross-border privacy and data protection legislation and regulation.
- The primary privacy threat arising from CASE vehicles is the gradual accumulation of seemingly insignificant practices for data collection and use by a variety of actors, and not malicious actors or individual instances of abuse.
- Insufficient cybersecurity measures cause unique safety risks and there are challenges in designing security protocols compatible across different vehicles and platforms, and scalable across potentially millions of cars.
- Technological capabilities to collect and analyze personal information are currently outpacing attempts to develop privacy and cybersecurity standards or regulation related to informed consent and data collection in the context of CASE vehicles.

CASE vehicles run on data. Data are what distinguish CASE from conventional vehicles; automated driving systems, connected vehicle services, and autonomous shared mobility services rely on the vast amounts of data generated and collected by CASE vehicles. CASE vehicle data are expected to provide a crucial input to advance both public- and private-sector interests. However, major risks to personal privacy and vehicle cybersecurity are associated with the data generated and collected by CASE vehicles. With respect to privacy, CASE vehicles are generating and collecting an increasing amount of personal information about individuals (Lawson *et al.*, 2015; SSCTC, 2018). Technological capabilities to collect and analyze personal information are currently far outpacing attempts to develop privacy standards or regulation related to informed consent and data collection in the context of CASE vehicles (Deloitte, 2018a). With respect to cybersecurity, there are serious risks that CASE vehicles could be hacked in order to disable or take control of a vehicle, jeopardize road safety, or disrupt traffic systems.

5.1 CASE Vehicle Data Uses

Many different sectors and industries are very interested in using the data generated and collected by CASE vehicles. In the public sector, CASE vehicle data present opportunities to better serve the public interest through improved safety, efficiency, accessibility, and equity in transportation systems; smarter and more sustainable urban planning; better transportation law enforcement; informed policy development; and directing funding to research that spurs innovation and economic growth (Deloitte, 2018a). In the private sector, these data offer opportunities for a wide variety of industries, including automakers and parts manufacturers, auto insurers, shared mobility fleet operators such as ride-hailing and car-sharing companies (including rental cars), third-party infotainment providers and app developers, as well as the direct monetization of CASE vehicle data through data selling and data brokering arrangements (Deloitte, 2018a). The global market opportunity for connected vehicle data monetization has been predicted to grow to US$33 billion by 2025 (Frost & Sullivan, 2017; as cited in Singh, 2017).

5.1.1 Driving and Safety

CASE vehicles rely on data for automated driving

Data used for performing automated driving functions include data generated by the vehicle's sensors, data collected from V2V and V2I communications, and map and location data. In addition, the machine learning algorithms used to develop automated driving capabilities require vast amounts of sensor data. These data are recorded from vehicles operated by human drivers, AI-controlled vehicles, and simulations. They are then used to train intelligent algorithms that learn to recognize features, objects, and behaviours based on identifying patterns in these datasets. Since this type of machine learning relies on the availability of large amounts of training data — typically far more data than a single research group or automaker can produce — a variety of existing datasets are available to researchers and automakers to train AI algorithms for CASE vehicles (Janai *et al.*, 2017; Yin & Berger, 2017). Moreover, some autonomous vehicle companies, including Waymo, Argo, and Aptiv, have begun to publicly release their datasets for use by other researchers (Abuelsamid, 2019). However, there are significant challenges related to the storage and management of the vast amounts of sensor and control data generated by CASE vehicles, and the sharing of training datasets may be hindered by issues around the proprietary rights of researchers and automakers to this potentially valuable intellectual property. Indeed, the automotive AI market was valued at approximately US$783 million in 2017, and is expected to reach US$11 billion by 2025 (MarketsandMarkets, 2017).

CASE vehicle data can be used to increase safety, but privacy issues arise with internal driver monitoring

CASE vehicle data can improve road safety by reducing the number of collisions caused by human error (Section 7.2). Moreover, these data offer additional ways to improve safety that are not directly related to performing the automated driving function. For example, data from CASE vehicles involved in collisions could be transmitted to first responders, providing precise information about the location of the collision and biometric information about the vehicle's occupants (Deloitte, 2018a). CASE vehicle data could also be used to identify safety hazards on the road, and transmit that information to the relevant authorities and to other vehicles (Anderson *et al.*, 2016; Deloitte, 2018a).

In 2019, the European Commission announced the mandatory installation of a number of connected vehicle safety measures by 2022, including electronic data recorders and speed limiters (EC, 2019). These speed limiters monitor whether the vehicle is exceeding the local speed limit, based on data from its GPS and cameras. If the vehicle is speeding, it will sound a warning to the driver and automatically slow down, although the system can be overridden by pressing on the accelerator (Topham, 2019). In addition, the vehicle's electronic data recorder records all breaches of the speed limit, raising questions about who has access to those data and under what conditions. EU member states and the European Parliament have not yet approved these new rules. CASE vehicle data can address some safety concerns that are unique to SAE Level 2 and 3 automation. As Level 2 and 3 vehicles require drivers to pay attention and be able to take over driving in a matter of seconds, automakers are beginning to increase the number of internal sensors that monitor the human driver. These include hand sensors on the steering wheel, interior cameras, facial recognition software, and eye and head tracking to determine whether the driver is paying attention (Kerr & Millar, n.d.). If the human driver is not sufficiently attentive, or takes their hands off the steering wheel, the vehicle provides warnings and eventually disengages the ADAS.

However, some argue that internal sensors are a mechanism to shift legal liability away from manufacturers of automated driving systems and towards human drivers (Kerr & Millar, n.d.). Although driver-monitoring sensors may improve safety, they also create unique privacy risks. While external sensors (e.g., cameras, LIDAR, radar, and geolocation) generally do not attempt to identify specific individuals or collect information about them,[8] internal sensors will undoubtedly increase the amount of personal information that CASE vehicles collect and "affect the nature and quality of privacy afforded to individuals inside their vehicles" (Kerr & Millar, n.d.). Data collected from internal sensors could be used to identify specific individuals, or determine ethnicity or other identifiable characteristics. They could also be used to determine whether a driver may have been intoxicated or tired in the case of a collision, hindering their ability to pay attention and take control of the vehicle when necessary. There is also the privacy risk of "function creep," in which internal sensors could be used for purposes other than monitoring driver attention, thereby creating new threats to privacy by collecting personal information without the knowledge or consent of individuals (Kerr & Millar, n.d.).

Internal driver monitoring raises a wide range of ethical and policy questions about the types and quantities of information collected, ownership of and access to that information, the legality of circumventing internal sensors dedicated to driver monitoring, and the relationship between public safety and individual privacy (Kerr & Millar, n.d.). Importantly, Kerr and Millar (n.d.) argue that safety and privacy do not have to be in tension with one another in a "Privacy by Design" approach (Section 5.4). For example, data could be stored or shared according to strict rules that are clear to the driver, with access limited only to investigative authorities in situations in which the data are required as part of a legal investigation. In addition, systems could be designed so data could be stored temporarily and never transmitted outside of the vehicle, and sensors could be designed to have the ability to monitor driver attention without making drivers personally identifiable. However, such an approach would likely require the establishment of rules or regulations for access to and use of data generated by internal driver-monitoring sensors (Kerr & Millar, n.d.).

5.1.2 Transportation System Management

CASE vehicle data can be used to improve transportation systems through data-sharing partnerships with shared mobility providers

While public-sector transportation authorities have long had access to real-time information about public transit, such as trains and buses, CASE vehicles offer the possibility of access to real-time data on the movement of a wider variety of vehicles (WEF, 2018b). This allows for the possibility of more efficient traffic flow

8 The German Federal Ministry of Transport and Digital Infrastructure has "speculated about the implications of future sensors that could distinguish between people and things — perhaps even to the point of identifying individuals as belonging to certain groups or categories." However, this is not yet possible with current technology (Kerr & Millar, n.d.).

management based on data collected from CASE vehicles about congestion and road and weather conditions. It also offers the opportunity to implement policies such as dynamic usage pricing and smart tolling through the analysis of data about traffic flow and vehicle behaviour (Deloitte, 2018a). However, all these benefits are contingent on the development of acceptable data ownership, access, and sharing arrangements. The growth of connected vehicles is likely to lead to a fundamental shift in the generation, collection, and ownership of transportation-related data, away from governments and towards the private sector (Ticoll, 2015). Currently, data sharing practices between the private and public sectors are complex and subject to ongoing development.

Several jurisdictions in Canada (including the cities of Toronto, Winnipeg, and Montréal and the provinces of Alberta, Ontario, and Quebec) have entered into mutually beneficial data-sharing partnerships with Waze, a Google-owned navigation app (Jackson, 2018). Under these arrangements, Waze provides a city with anonymized data from local Waze users; the city provides Waze with access to real-time city-controlled transportation data such as road closures, traffic conditions, accident locations, and construction zones (Rider, 2017). The *Waze for City Data* program does not involve any financial exchange and is based on the free sharing of data. Furthermore, Quebec recently passed a law requiring automobile-based geolocation devices (including those in taxis, rental cars, and smartphones used for shared mobility services such as Uber) to transmit real-time location data to local municipalities, municipal transit agencies, or transportation companies designated by the government (Gov. of QC, 2019).

The Los Angeles Department of Transportation (LADOT) has developed an application programming interface (API) tool, known as the *Mobility Data Specification* (MDS), that allows the city to collect real-time vehicle data from shared mobility service providers (Pyzyk, 2019). MDS monitors some shared vehicles, such as dockless scooters, bikes, taxis, and buses, but can eventually be extended to include ride-hailing or car-sharing services. LADOT requires companies to provide real-time information about the number, location, and condition of all vehicles in use at a given time, and has released MDS publicly as an open-source standard that can be adopted by others (LADOT, 2018). To date, 50 cities in the United States and another 12 internationally have adopted MDS (Hawkins, 2019c). While LADOT claims that MDS does not collect any personal data (LADOT, 2019), MDS has been criticized for lacking sufficient privacy protections, as well as for allegedly violating California privacy law (OTI & EFF, 2019). In addition, Uber has threatened to sue the city of Los Angeles over the program, arguing that the data-sharing requirements compromise customer expectations for data privacy and security (Hawkins, 2019a).

CASE vehicle data may be used to improve transportation equity and accessibility

CASE vehicle data may improve transportation accessibility and equity for people living in rural, remote, or underserved areas; seniors and children; and people with mobility-limiting disabilities (Section 6.3). While higher levels of automation (i.e., SAE Levels 4 and 5) will have the greatest impact on accessibility and equity, CASE vehicle data about specific individuals could be used to program vehicles to accommodate varying levels of driver ability (Deloitte, 2018a). However, CASE vehicles will have to be inclusively designed to realize these benefits.

Governments will have an important role to play in using CASE vehicle data to improve equity and accessibility in transportation, particularly as profit-oriented private sector mobility providers are unlikely to achieve such outcomes without government intervention (WEF, 2018b). For example, the potential for low-cost mobility through CASE vehicle fleets holds some promise in addressing accessibility and equity issues in the planning and design of municipalities. Data-sharing arrangements between private mobility and smart infrastructure providers and municipal governments may help to provide urban planners with information necessary to assess community needs, address transportation challenges, and identify areas for improvements in accessibility in smart cities. Such information could then be used to create transit plans that take into account areas predicted to be underserved in the near future (e.g., Mayaud *et al.*, 2019). However, while CASE vehicles may improve transportation equity and accessibility by providing mobility to individuals who do not have alternative transportation options, lack of robust privacy protections could force such individuals into a situation in which they have to choose between a mobility service that tracks their movements and collects their personal data, or no mobility at all (Collingwood, 2017).

5.1.3 Other Uses for CASE Vehicle Data

OEMs may use CASE vehicle data for a wide variety of purposes

Automakers have access to a wide range of CASE vehicle data, including customer account information; data about vehicle health, driver behaviour, vehicle location, and in-vehicle activities; and any biometric or health data collected by the vehicle. In addition, OEMs that produce telematics and infotainment systems can access all data passing through those systems, including data from any connected smartphones displayed through the vehicle's infotainment system (Lawson *et al.*, 2015).

Automakers may use these data for a variety of purposes, such as monitoring vehicle health, performing remote diagnostics for the purposes of preventative maintenance, and offering over-the-air software updates, thereby reducing recall and warranty costs (Lawson *et al.*, 2015; Deloitte, 2018a). Furthermore, automakers are focusing on the use of data collected from CASE vehicles to provide customized or personalized driving experiences, as well as managing fleets of shared vehicles (Deloitte, 2018a). Automakers may also directly monetize CASE vehicle data through data sharing and data brokering arrangements. For example, Otonomo, a connected vehicle data marketplace and services platform, collects data from automakers and fleet operators. It then aggregates, anonymizes, and standardizes the data before selling it to a number of organizations, including automakers, insurers, urban planning authorities, financial institutions, and more (Deloitte, 2018a). This arrangement helps automakers commercialize their connected vehicle data (Gogolek, 2019).

The British Columbia Freedom of Information and Privacy Association (BCFIPA) has raised concerns about the privacy policies of automakers selling connected vehicles in Canada. A 2015 BCFIPA report found that connected vehicle service providers were "failing to meet the standards of Canadian law in respect of openness, accountability, individual access and limiting collection, retention, use and disclosure of customer data," and that the industry was "violating Canadian data protection laws" (Lawson *et al.*, 2015). In its 2019 update of the study, BCFIPA found that although the situation had significantly improved since 2015, most OEM privacy policies were "still inadequate when compared to all major data protection principles and requirements under Canadian data protection law" (Gogolek, 2019).

Aftermarket parts and service providers will need access to CASE vehicle data

Automotive aftermarket parts and service providers are interested in the opportunities that CASE vehicle data present for innovation in manufacturing, distribution, and repair services. For example, these companies could use vehicle health data and remote diagnostics to improve efficiency and effectiveness in vehicle maintenance and repair services by pre-emptively ordering parts and preparing for repairs ahead of a customer's arrival at a service centre (AIA Canada, 2017; McKinsey, 2018a). Such innovations in diagnostics could be especially helpful in rural communities, where service shops may need more time to source parts. Big data analytics is also seen as a significant opportunity for new sources of revenue and optimizing value chains in the aftermarket industry (McKinsey, 2018a). However, it is difficult for aftermarket parts and service providers to get access to the data generated and collected by CASE vehicles, which is often controlled by automakers and not widely shared. Access to connected vehicle data is a point of tension between OEMs and independent automotive aftermarket parts and services companies in Canada (AIA Canada, 2017). After releasing a discussion paper and holding consultations with various industry stakeholders, the Government of Australia recently announced that it will introduce legislation requiring the sharing of motor vehicle service and repair data (AAAA, 2019; Gov. of Australia, 2019). AIA Canada has suggested that a similar law would be beneficial to the aftermarket industry in this country (J.-F. Champagne, personal communication, 2019). The *Canadian Automotive Service Information Standard* addresses access to data from onboard computers, but the agreement does not cover connectivity (CASIS, 2009).

The success of future shared mobility services will depend on access to CASE vehicle data

Shared mobility services depend on data, not only for hailing, booking, and payment, but also for efficiently managing fleets of vehicles. Analysis of CASE vehicle data could identify gaps and opportunities in meeting users' needs (MA, 2018), and help service providers to reduce the number of "empty miles" (i.e., distance the vehicle travels without a passenger) through the analysis of use patterns (Deloitte, 2018a). Data-related barriers to the development of MaaS include poor data quality and a lack of data standardization, system interoperability, consumer data portability, and economic incentives to make these data more widely available (MA, 2018). Disputes about data ownership and access in this area are ongoing; for example, some rental car companies argue that vehicle ownership should grant the right to access the data generated by that vehicle (SSCTC, 2017a). They believe that since many automakers and CASE vehicle manufacturers intend to own and operate their own fleets of vehicles while also selling vehicles to other fleet operators, manufacturers could restrict the access to data for third-party fleets, thereby gaining a competitive advantage (SSCTC, 2017a). Indeed, ownership of and access to data may determine market dominance in the CASE vehicle mobility ecosystem (MA, 2017).

Issues also arise in relation to the ability of customers to delete their personal data from rental and shared vehicles. These data can include a wide variety of personal information, including personal communications, contacts, and web browsing data, infotainment preferences, and any information stored on the driver's smartphone that could be displayed through the infotainment system. A 2017 report found that, without exception, car rental and car sharing companies claimed that users were responsible for deleting their own data before returning the vehicle and for informing any passengers that the vehicles would collect and store their information. However, companies typically did not inform customers that their personal data might be collected and stored in this way (PI, 2017).

CASE vehicle data present a significant economic opportunity for infotainment providers

One of the most lucrative opportunities for the monetization of CASE vehicle data is in infotainment, for established OEMs as well as for new entrants. Infotainment systems generate data on the information and entertainment preferences of a vehicle's users, including streaming audio and video, internet browsing, news, communications (including phone, email, texts, social media, and contacts), and app use (Lawson *et al.*, 2015). Business opportunities include providing in-vehicle add-on features (i.e., in-car apps) (Deloitte, 2018a) and marketing and customized advertising based on infotainment data (Deloitte, 2019). In-vehicle infotainment also offers opportunities for streaming audio and video content providers — beyond air travel, few other opportunities exist for content providers to have a captive audience, potentially for hours at a time. A 2019 report estimated the automotive infotainment market at approximately US$18.8 billion in 2018, and projected it to reach US$53.3 billion by 2026 (Reports and Data, 2019). Experts suggest that infotainment may help to increase demand for CASE vehicles through a "synergistic" effect wherein each technology increases the demand for the other (Anderson *et al.*, 2016).

5.2 Privacy Implications of CASE Vehicle Data

The enormous volumes and new types of data generated and collected by CASE vehicles may cause risks to personal privacy. The data collected by CASE vehicles can contain sensitive personal information that could be used to profile, predict, and manipulate the behaviour of CASE vehicle users (Collingwood, 2017). Furthermore, current practices in the CASE vehicle ecosystem may prevent individuals from retaining control over their personal information. Importantly, the risks to privacy arising from CASE vehicles are not simply due to malicious actors or individual instances of abuse; rather, the primary threat is the gradual accumulation of seemingly insignificant practices for data collection and use by a variety of different actors (Lawson *et al.*, 2015).

5.2.1 New Volumes and Types of Data

CASE vehicles generate both enormous volumes and new types of data. According to one analysis, each connected vehicle is predicted to transmit around 8 GB of data per day by 2023 (Obstfeld, 2019). By comparison, mobile data traffic per smartphone is estimated to rise to an average of 1.6 GB per day by 2024, meaning that each connected vehicle could generate more than five times as much data as a smartphone (Obstfeld, 2019).

CASE vehicles generate and collect new types of data about the vehicle and its passengers

In addition to vehicle data (such as type, make, and model) and telematics data (e.g., vehicle speed, location, performance, and diagnostic information), CASE vehicles may also generate or collect personal data about the vehicle's passengers. This could include behavioural data, biometric and health data, personal communications (voice, text, email, and social media), contacts, web browsing data, infotainment preferences (e.g., audio and video streaming, app use), and more (Lawson *et al.*, 2015; Deloitte, 2018a). Furthermore, V2X technologies allow this information to be transmitted to other vehicles, infrastructure, and a wide variety of organizations (Toral, 2018).

Existing technologies such as smartphones also generate and collect similar types of personal data about their owners. Consequently, some experts and policymakers have suggested that CASE vehicles should be treated similarly with respect to the consent, collection, and use of data (Deloitte, 2018a). Other experts disagree, arguing that "[t]he breadth and depth of personal data that can be culled from Connected Cars is enormous and goes significantly beyond that already available via mobile devices, both in quality and in quantity" (Lawson *et al.*, 2015). For example, CASE vehicles have a far greater number and variety of sensors, including internal sensors that can monitor passengers; as a result, they may present unique privacy risks not associated with smartphone use. Nevertheless, while CASE vehicles produce new types and greater volumes of personal data than existing devices, and provide new examples of technological risks to personal privacy, the underlying legal, ethical, and social issues are largely the same. Technology-driven privacy risks are not unique to CASE vehicles, but may be exacerbated by them.

CASE vehicles collect personal and non-personal information that may be highly revealing

CASE vehicles generate and collect both personal and non-personal data. *Personal data* are about an identified or identifiable individual, whereas non-personal data cannot be linked to a specific person (Lawson *et al.*, 2015; McMillan, 2016; Deloitte, 2018a). In the context of CASE vehicles, non-personal data may include sensor data, as well as information about traffic flows, road conditions, and weather (Deloitte, 2018a). However, even seemingly non-personal information, such as sensor or geolocation data, can potentially be linked to the identity of a particular individual and, to that extent, may be considered personal information (McMillan, 2016; Lee, 2017). Location data could present serious privacy concerns, as well as implications for surveillance or theft, as it could be used to track individuals' travel patterns and to predict or even manipulate their future behaviour (Collingwood, 2017; Parkinson *et al.*, 2017).

Big Data analytic techniques — i.e., the large-scale collection, aggregation, processing, and analysis of vast amounts of data from a wide variety of sources — are becoming common in the connected vehicle ecosystem as industry stakeholders view these data as a key revenue stream (Lawson *et al.*, 2015). Some of the uses for Big Data directly relate to improving the safety and efficiency of CASE vehicles (OECD/ITF, 2018). However, as the BCFIPA points out in Lawson *et al.* (2015):

> *Separately, each piece of data about a person's vehicle use, driving routes and destinations, or use of in-vehicle communications and infotainment services reveals something about that person. Combined or accumulated over time, such data — even if each piece seems innocuous in isolation — becomes highly revealing. It can divulge the identity of an otherwise unidentified person, as well as that person's habits, routines and social circle. It can be used to ascertain the person's religious and political associations. It can show when a person deviates from their normal routine, develops a health problem, or engages in activities that, if known, could harm their reputation.*

Furthermore, it is common practice for connected vehicle automakers and service providers to treat aggregated data as non-personal information, and thus not subject to privacy laws, a practice that BCFIPA refers to as "misleading and legally suspect, at best" (Lawson *et al.*, 2015).

5.2.2 Data Collection, Access, and Ownership

CASE vehicle data collection, access, and ownership issues are still being addressed (Faisal *et al.*, 2019). Governments and standard-setting organizations will need to collaborate with stakeholders, including automakers, mobility service providers, insurers, and software developers to develop frameworks to manage these issues. As noted, CASE vehicles may collect vast amounts of personal data. Moreover, the practice of collecting personal data for secondary uses (i.e., for uses not directly related to the stated purpose for which they were collected) is one of the main business models for connected vehicle services (Lawson *et al.*, 2015). Although data collection for secondary uses is illegal under Canadian federal law (GC, 2000), a 2019 review of privacy policies of OEMs selling connected vehicles in Canada found that most OEMs provided only vague descriptions of the purpose for the collection and use of personal information, and generally offered no way to opt out (Gogolek, 2019). A report by the U.S. Government Accountability Office (2017) came to similar conclusions: the privacy policies of OEMs selling connected vehicles in the United States regularly used unclear and vague language; nearly all failed to list the purposes for which data would be collected or how those data would be shared with third parties; and most did not offer any way to opt out of data collection.

OEMs may have access to a wide range of vehicle data, including customer account information, vehicle health data, driver behaviour data, vehicle location data, and any biometric or health data collected by the vehicle, as well as data from telematics and infotainment systems, including data from any connected smartphone.

Auto Dealers obtain data directly from the customer. In addition, they may have access to additional personal information that the automaker shares with them. Dealerships may also use aftermarket telematics systems to obtain more data about their customers.

Rental Car & Car-Sharing Services may track vehicle location, vehicle health data, and customer driving behaviour. They may also collect additional customer data if they offer infotainment services in their vehicles.

Mobile Network Operators have access to all metadata about their customers, both via smartphones and the connected vehicle, as well as a user's contacts.

Call Centres that offer services such as roadside assistance and infotainment may record customer calls and share them with third parties.

Figure 5.1 Who Has Access to What Data?

Lawson *et al.* (2015), Deloitte (2018a), Gogolek (2019)

Lenders/Financing Services may have access to certain driver behaviour and vehicle location data via telematics devices.

Government Agencies may have access to both historical and real-time telematics and location data through data-sharing arrangements with mobility service providers. In addition, some CAV data may be held by foreign governments.

Insurers may have access to driver behaviour and vehicle location data via telematics devices, to assess risk and provide custom rates.

Aftermarket Telematics Service Providers may have access to vehicle and driver behaviour, as well as location data. They also have access to data about customer use of any additional services (e.g., roadside assistance, concierge services) that they offer.

Mobile Device System Providers (e.g., Google Android, Apple iOS) have access to all data in a user's mobile devices, certain vehicle and driver behaviour data generated by vehicle-connected mobile applications, and infotainment data connected to the device.

Third Party Application Providers have access to data collected or generated through use of their applications. Providers also commonly gather additional personal data, either directly from users or via social networking sites to which their services are linked.

It is unclear who owns the data generated and collected by CASE vehicles

Multiple entities — including private-sector companies, government agencies, and members of the public — may hold CASE vehicle data, with competing claims of ownership and no clear way to resolve disputes (Collingwood, 2017; Deloitte, 2018a). Moreover, data ownership issues become more complicated with shared mobility, as a variety of different actors, including fleet operators, vehicle owners, and vehicle users, may have a vested interest in the data generated and collected by a CASE vehicle (Deloitte, 2018a). The situation becomes yet more complex when dealing with jurisdictional issues about data stored in different countries, which may be subject to different laws and regulations around legal ownership (ITAC, 2018). According to Kerr *et al.* (n.d.), the question of who owns CASE vehicle data is often less useful than questions about who holds or controls the data, and who should be able to legally access it.

A wide variety of different entities and organizations may have access to different types of data generated and collected by CASE vehicles (Figure 5.1). Additionally, any of these entities may enter into data-sharing agreements with any number of others; for example, automakers may share customer data with network service providers and infotainment applications developers, and insurers may partner with telematics service providers to provide usage-based insurance rates (Lawson et al., 2015).

The public is concerned about the privacy risks of CASE vehicles

The Canadian public appears to be wary of the privacy risks associated with CASE vehicles, to the extent that they are aware of those risks at all. A CAA (2017) survey found that fewer than half of all respondents were aware of the range of data that could be collected by connected vehicles, although over 80% were concerned about the privacy risks of this technology and believed that consumers should have exclusive rights over control and access to their data. Moreover, nearly 90% agreed that the consumer should be able to decide with whom their data are shared. Respondents were most receptive to allowing independent auto mechanics and roadside assistance providers to access certain vehicle data, and least receptive to retailers and marketers having such access (CAA, 2017). A 2019 study by Environics Research for Transport Canada also found concerns among Canadians about data privacy and security in CASE vehicles, with 73% either strongly or somewhat agreeing with the idea that "[w]hen vehicles become more automated, system security and data privacy will become more of a concern" (TC, 2019b). However, it is unclear whether public concerns over privacy will negatively affect adoption of CASE vehicles; for example, privacy concerns related to smartphones and the internet have had little impact on consumer uptake of the technology (Collingwood, 2017).

5.3 Data Privacy Legislation, Regulation, and Trade Agreements

The privacy risks associated with CASE vehicle data may make it necessary to quickly establish standards around the transmission, storage, and use of data; cross-border data flows; and best practices for compliance with privacy law in different jurisdictions (Deloitte, 2018a). Ownership, access, and control of data will need to be clearly defined, via either voluntarily adopted industry standards or government-imposed legislation or regulations. Existing privacy laws may be inadequate to deal with the novel issues presented by CASE vehicles (Lee, 2017). Lack of robust and reliable data privacy and security standards may be a barrier to CASE vehicle deployment.

5.3.1 Current Legislation and Regulation

While the federal government and some provincial and territorial governments have enacted data privacy legislation, no legislation or regulations in Canada deal specifically with the collection and use of personal information generated, collected, or transferred by CASE vehicles (Lawson *et al.*, 2015; Deloitte, 2018a). Two main pieces of federal legislation address data privacy (OPC, 2018): the *Privacy Act*, which applies to personal information handled by the federal government (GC, 1985), and the *Personal Information Protection and Electronic Documents Act* (PIPEDA), which regulates how private-sector organizations handle personal information (GC, 2000). In addition, the Standards Council of Canada (SCC) has approved the development of a series of new data governance standards that specify minimum requirements for data collection, access, and use, as well as data sharing practices among organizations, data privacy protection, cybersecurity, and more (SCC, 2019). Such standards would apply to data generated and collected by CASE vehicles.

Unlike Canada, the United States has no federal data protection legislation, and privacy laws vary by state (Lawson *et al.*, 2015; USGAO, 2017). Federal privacy legislation (e.g., the *Driver's Privacy Protection Act*, the *Electronic Communications Privacy Act*, and the *Federal Communications Act*) is generally inapplicable to CASE vehicles (DPR, 2017). However, several U.S. states have enacted legislation around data privacy issues related to data retrieved from event data recorders that record sensor and diagnostic data prior to collisions (Toral, 2018). The Federal Trade Commission (FTC) enforces United States federal law requiring companies to comply with their stated privacy policies, but no federal law or regulation sets standards for such policies. Although the FTC could use its authority over data privacy and data security issues for CASE vehicles to bring legal action against automakers for non-consensual uses of customers' personal data or for violating their stated privacy policies, as of 2016, the FTC had not brought any such actions against any CASE vehicle manufacturers or associated third parties (Lee, 2017; USGAO, 2017).

In the EU, the *General Data Protection Regulation* (GDPR), which came into effect in 2018, protects personal data (EU, 2016). While the GDPR does not contain provisions specific to CASE vehicles, in 2017 the French data protection authority (Commission nationale de l'informatique et des libertés) published a guide on the treatment of personal data in connected vehicles that provides best practices for compliance with the GDPR and French data protection law (CNIL, 2017).

Voluntary best practice codes may be insufficient to protect privacy in CASE vehicles

In its 2018 report, the Canadian Senate Standing Committee on Transport and Communications suggested that it was too early in the development of the CASE vehicle industry to determine whether data privacy regulation specific to CASE vehicles was necessary or whether voluntary guidelines would be sufficient to protect privacy (SSCTC, 2018). The Government of Canada's response was to commit to working towards the "development of an industry-specific code of best practices for privacy protection" rather than regulations, to provide flexibility and adaptability to future technology development (GC, 2018b). In addition, a 2019 report by the Policy and Planning Support Committee Working Group on Automated and Connected Vehicles of Canada's Council of Ministers of Transportation and Highway Safety, calls for governments to work with stakeholders to develop an industry-specific code of best practices for collecting and using personal information in the context of CASE vehicles (PPSC, 2019).

However, as the federal government points out in its recent proposal to modernize PIPEDA, industry-specific codes of best practices "can be at best meaningless and at worst deceptive" without appropriate oversight (ISED, 2019b). Indeed, a report by the U.S. Government Accountability Office that examined a self-regulatory framework for vehicle data privacy developed by United States automakers in 2016, known as the *Consumer Privacy Protection Principles: Privacy Principles for Vehicle Technologies and Services*, found that these principles failed to provide sufficient guidance for automakers and did not sufficiently protect consumers' privacy (USGAO, 2017). Furthermore, a survey by the CAA (2017) found that Canadians were overwhelmingly (81%) in support of clear and enforceable rules to protect the privacy of personal information generated and collected by CASE vehicles. The vast majority of respondents did not think that voluntary industry commitment to privacy would be sufficient, with only 11% in support (CAA, 2017).

Thus, regulatory action may be required to ensure that data privacy is protected in CASE vehicles.

5.3.2 Implications of Trade Agreements

CASE vehicles raise issues around data sovereignty and cross-border data flows

Given the integrated nature of the North American automobile industry, a concerted effort has been made to harmonize vehicle safety and emissions standards (Lawson *et al*., 2015). However, a comparable push to harmonize data protection standards or regulations has not yet occurred (Lawson *et al*., 2015). This presents a challenge because CASE vehicles can be used to travel across national borders into countries that have different requirements around data protection and privacy. Thus, CASE vehicle manufacturers and developers may need to develop data collection and management practices that are sensitive to different privacy laws in different jurisdictions (McMillan, 2016; TRBOT, 2020).

Issues related to data sovereignty will undoubtedly arise in the context of CASE vehicles, because many of the companies involved in Canada's CASE vehicle ecosystem are U.S.-based and the Canada-U.S. auto sector is highly integrated. Personal information collected by CASE vehicles operating in Canada may be stored outside of the country, and therefore subject to different privacy and data protection laws (Gogolek, 2019). Canadian courts have addressed some of these issues for other technologies. For example, the Supreme Court of Canada ruled in *Douez v. Facebook* (2017) that provisions in online user agreements that require users to resolve any disputes in international jurisdictions, regardless of the user's geographical location, are unenforceable (Kerr & Millar, n.d.).

In addition, Canada is party to several international trade agreements that deal explicitly with issues around data, privacy, and cybersecurity, such as the *Canada-United States-Mexico Agreement* (CUSMA) and the *Comprehensive and Progressive Agreement for Trans-Pacific Partnership* (CPTPP). Both agreements contain relevant provisions for CASE vehicle data, including the protection of personal information and cybersecurity, the cross-border transfer of data, data sovereignty, and source code and algorithmic transparency (GC, 2016, 2018a). However, in the case of CUSMA, these provisions have become one of the most criticized areas of the agreement (Balsillie, 2020; de Beer, 2020).

Both CUSMA and CPTPP require that countries not restrict the cross-border transfer of information, including personal information, unless the restriction "is necessary to achieve a legitimate public policy objective," does not constitute "a means of arbitrary or unjustifiable discrimination or a disguised restriction on trade," and is not greater than necessary to achieve this objective (GC, 2016, 2018a). However, it is not clear if organizations in Canada must obtain an individual's consent before transferring their personal information to an organization outside the country (Leblond, 2019). Both agreements prohibit countries from requiring that data be stored in their own country as a condition of market access. However, in CPTPP, this provision contains an exception for a "legitimate public policy objective" that does not appear in CUSMA. It is not entirely clear what a "legitimate public policy objective" includes in this context, although some privacy experts have argued that it may not include the protection of personal information (Leblond, 2019).

Governments may want access to the source code and algorithms that control CASE vehicles to verify that the vehicles meet their regulatory standards (Ticoll, 2015). It is likely that any future litigation for CASE vehicles involved in collisions will require understanding the vehicle's decision-making algorithms to determine liability (Scassa, 2018). In addition to the significant technical challenges associated with assessing immensely complex CASE vehicle source code and algorithms, there are also challenges related to Canada's trade agreements. Both CUSMA and CPTPP stipulate that countries may not require access to the source code of software as a condition of its import, distribution, or use (Leblond, 2019). However, CPTPP allows countries to require source code modification to comply with their laws or regulation. CUSMA does not contain an analogous provision on allowing requests for source code modification, meaning that, in principle, a Canadian request for algorithmic modification to CASE vehicle software for the purposes of complying with Canadian law or regulation "could be challenged under CUSMA as a protectionist measure discriminating against the American or Mexican producer of the software or application" (Leblond, 2019). However, CUSMA does allow a "regulatory body or judicial authority" to require companies to make source code available for purposes of "a specific investigation, inspection, examination, enforcement action, or judicial proceeding, subject to safeguards against unauthorized disclosure" (GC, 2018a). In addition, the scope of this provision under CPTPP is limited to "mass-market software or products containing such software," and exempts software used for "critical infrastructure," whereas CUSMA does not make this distinction (GC, 2016). It is not clear whether or what V2I-enabled infrastructure would be covered under this distinction.

5.3.3 Models of Privacy Protection for CASE Vehicle Data

The consent model of privacy protection is currently used for connected vehicles

Some argue that it is often unclear whether users are able to give meaningful, informed consent to data collection in the context of connected vehicles, which requires individuals to have a basic understanding of how their information will be collected, used, and shared (Lawson *et al.*, 2015). For example, given the proliferation of complex and lengthy "conditions of use" agreements required to own or use a connected vehicle, it is not clear whether users are able to adequately inform themselves of the conditions under which their information will be collected and used. As Lawson V2I-enabled infrastructure *et al.* (2015) point out, an individual purchasing a connected vehicle must agree to the privacy policies of a variety of different entities, such as OEMs, dealerships, manufacturers of third-party infotainment or telematics systems, third-party connected car app developers, mobility service providers, mobile device providers (if the connected vehicle connects to the user's smartphone), financing services, and insurance companies. Individuals are expected to be fully aware of all the various ways that their personal data might be collected, used, or shared by any and all of these entities, as set out in their respective privacy policies. As a result, they may not understand who is collecting, accessing, and using their personal data, under what conditions, and for what purposes (Lawson *et al.*, 2015). Indeed, *Canada's Digital Charter* explicitly recognizes these shortcomings, stating that "[c]urrent consent-based models with complex and lengthy privacy policies are inadequate and do not help to build trust" (ISED, 2019a).

Rather than explicitly asking customers to opt into data collection, most OEMs selling connected vehicles in Canada rely on a form of implied consent in which individuals are assumed to be giving consent when they use the service in question and are not always offered the option to opt out (Gogolek, 2019). This situation gives rise to important ethical and policy questions on the legitimacy of default opt-ins to data collection in contracts, such as whether such arrangements provide consumers with any choice, and how they might affect privacy rights more generally.

Privacy by Design is a promising framework to address privacy issues for CASE vehicles

Many academics, private sector companies, governments, and other stakeholders have advocated for the adoption of a Privacy by Design (PbD) framework to proactively address privacy issues in the context of CASE vehicles (Ticoll, 2015; McMillan, 2016; Deloitte, 2018a). The concept of PbD (Cavoukian, 2011) is based on the idea that "privacy cannot be assured solely by compliance with legislation and regulatory frameworks; rather, privacy assurance must become an organization's default mode of operation" (IPCO, 2013).

In Canada, the Parliamentary Standing Committee on Access to Information, Privacy and Ethics has recommended amending PIPEDA to incorporate PbD as a central principle (Zimmer, 2018). *Canada's Digital Charter* also tacitly recognizes PbD, stating that a "commitment to privacy and maintaining trust [...] should be built in to the design of digital systems from their inception" (ISED, 2019a). In Europe, the GDPR incorporates the principles of PbD (Article 25) (EC, 2016), and the U.S. Federal Trade Commission has recommended that data-collecting organizations adopt the PbD framework (FTC, 2012). German federal and state data protection authorities have called on auto manufacturers to observe the principles of PbD in developing new vehicles and services (Lawson *et al.*, 2015). In 2017, the 39th International Conference of Data Protection and Privacy Commissioners, composed of 119 privacy and data protection authorities from around the world, adopted a non-binding *Resolution of Data Protection in Automated and Connected Vehicles* (ICDPPC, 2017). The Resolution urges standardization bodies, public authorities, vehicle and equipment manufacturers, personal transportation services and car rental providers, and providers of data-driven CASE vehicle services to adopt the PbD framework (as well as 16 additional data privacy and security principles) in the development of CASE vehicle technology.

5.4 Cybersecurity and CASE Vehicles

Unique cybersecurity considerations, challenges, and risks are associated with CASE vehicles (McMillan, 2016). It has been estimated that current non-autonomous vehicles have over 50 attack points that can be exploited by hackers; in CASE vehicles the number of attack points is substantially higher (Saed *et al.*, 2019). Furthermore, the consequences of hacking CASE vehicles may be far more serious than with conventional vehicles. A 2015 report showed that 16 major automakers failed to address the possibility of hackers gaining access to the systems of a connected vehicle, and that nearly all connected vehicles were then vulnerable to at least one (and in many cases multiple) wireless entry points (Markey, 2015). There were also inconsistent and haphazard cybersecurity approaches across all automobile manufacturers, with some having no security measures at all (Markey, 2015). As levels of vehicle automation increase, so too do the dangers associated with cyberattacks.

5.4.1 CASE Vehicle Vulnerabilities

CASE vehicles may be vulnerable to attacks through V2X and physical connections

Any device connected to a communications network can potentially be vulnerable to cyberattacks. CASE vehicles are not only connected to wireless networks (e.g., V2N), but also potentially to other vehicles on the road (V2V), roadside infrastructure (V2I), and other mobile devices both inside (via Bluetooth) and outside the vehicle (V2P). This connectivity opens CASE vehicles to the potential of large-scale and highly damaging attacks (Parkinson *et al.*, 2017). Moreover, when multiple devices are connected in this way, a security vulnerability in any one of them may be exploited to compromise all of them (McMillan, 2016; Kennedy, 2017). Additional opportunities for cybersecurity breaches arise because CASE vehicles are fundamentally designed to travel, and to collect and share information from a wide variety of sources as they move (McMillan, 2016). V2X communications are not the only entry point for CASE vehicle hacking; malicious actors could gain access to CASE vehicles through physical connections such as a USB interface or the vehicle's onboard diagnostics port (Parkinson *et al.*, 2017; Saed *et al.*, 2019). Malware could also be inadvertently introduced through physical connections at dealerships or auto mechanics (Lee, 2017; Saed *et al.*, 2019).

Without robust security, CASE vehicles risk being controlled or disabled by cyberattacks

Insufficient cybersecurity measures can cause unique safety risks for CASE vehicles, particularly when hackers are able to interact with the vehicle's control systems (Ticoll, 2015; Lee, 2017). It has been demonstrated that third parties have sometimes been able to wirelessly control certain driving functions in conventional vehicles with an internet connection, such as acceleration, braking, and turning, all while the vehicle is travelling at any speed (e.g., Valasek & Miller, 2015; Greenberg, 2016). In such situations, a vehicle's driver or passengers may be unable to intervene (Lee, 2017; Taeihagh & Lim, 2019). It has been suggested that a failsafe override mechanism that allows occupants to take some degree of control of the vehicle may be necessary for this reason (Kennedy, 2017). The behavioural responses of CASE vehicle users in the event of a cyberattack is an ongoing area of research. While a single CASE vehicle under the remote control of a malicious actor could be very dangerous, V2V communications may allow hackers to extend their reach and take control over multiple vehicles simultaneously, turning them into a "vehicular botnet" (Saed *et al.*, 2019).

CASE vehicles may also face cyberattacks that attempt to disable the vehicle or its sensors, or cause it to malfunction. For example, an attack could interfere with GPS or V2X communication signals using a signal jammer or through a denial-of-service (DoS) attack, preventing the vehicle from receiving critical messages (Petit & Shladover, 2014; Parkinson *et al.*, 2017; Saed *et al.*, 2019). Alternatively, an attacker might send false GPS signals or fake V2X safety messages ("spoofing") to mislead the vehicle or cause disruption to traffic flows (Petit & Shladover, 2014; Parkinson *et al.*, 2017; Saed *et al.*, 2019; Taeihagh & Lim, 2019). In addition, CASE vehicles may be vulnerable to low-tech hacks that disable or interfere with the vehicle's sensors, such as shining a bright light into a CASE vehicle's cameras or a laser into its LIDAR unit (Petit & Shladover, 2014; Parkinson *et al.*, 2017). Similarly, CASE vehicle sensors can be intentionally misled by the use of certain types of simple markings on roadways or signs (Eykholt *et al.*, 2018; TKSL, 2019). However, attacks on vehicle sensors may be mitigated by using multiple modes of sensing (e.g., cameras, LIDAR, and radar) combined through sensor fusion (Cui *et al.*, 2019).

Much of the data generated and collected by CASE vehicles could be used for identify theft, surveillance, blackmail, and other types of harm (Lawson *et al.*, 2015). CASE vehicles also could be subject to ransomware attacks — malicious software that prevents authorized users from accessing their data unless they agree to pay a ransom (SSCTC, 2018). Concerns have arisen regarding how and where different types of CASE vehicle data are stored, and for how long, as well as the nature of the cybersecurity measures protecting these data (Lee, 2017).

Preventing cyberattacks on CASE vehicles presents several challenges

Several researchers have provided a comprehensive review of known cybersecurity vulnerabilities in CASE vehicles, potential mitigation techniques, and ongoing research efforts (Petit & Shladover, 2014; Parkinson *et al.*, 2017; Saed et al., 2019). However, the specific security vulnerabilities in CASE vehicle cybersecurity are difficult to predict, due to both the newness of the technology (Lee, 2017), as well as its complexity (Parkinson *et al.*, 2017).

The primary factor currently contributing to cybersecurity vulnerabilities in CASE vehicles is that the technology is in its early stages, and security standards and protocols are still being developed. Emerging technologies such as blockchain and public key infrastructure may reduce cybersecurity risks (SSCTC, 2018). Another suggested measure to improve vehicle cybersecurity is segmenting, in which internal systems are separated as much as possible, so that a breach of one system does not compromise the system as a whole (Kennedy, 2017). For example, it may be necessary for systems critical to safety and driving functions to be segregated from systems for infotainment or navigation (Lee, 2017). New encryption and authentication techniques will likely be required in order to ensure vehicular cybersecurity (Saed *et al.*, 2019). Some automakers are already working with "white hat" hackers (computer security experts who test the security of a company's ICT systems by attempting to disable them) to identify and fix potential vulnerabilities (SSCTC, 2018).

However, independent researchers are unable to scrutinize existing cybersecurity measures. In the United States, the *Digital Millennium Copyright Act* protects copyright holders of vehicle software from disclosure, thus preventing researchers from examining potential security vulnerabilities (Ticoll, 2015). There have been proposals to exempt vehicle software from these protections for the purposes of cybersecurity research (Brachmann, 2015). In 2015, the U.S. Copyright Office granted a partial exemption for vehicle software, allowing authorized owners of the vehicle to circumvent copyright protections "to allow the diagnosis, repair or lawful modification of a vehicle function," but the exemption excludes telematics and infotainment systems (Brachmann, 2015). Moreover, international trade agreements, including CUSMA and CPTPP, may prevent scrutiny of the algorithms used in CASE vehicles.

Some best practices and guidelines for CASE vehicle cybersecurity have been developed by international organizations. For example, the Society of Automotive Engineers' *Cybersecurity Guidebook for Cyber-Physical Vehicle Systems* provides guidance and best practices for vehicular cybersecurity (SAE, 2016). Similarly, in 2017 the European Automobile Manufacturers Association (ACEA) released guidance for CASE vehicle cybersecurity that emphasizes the need for a "cybersecurity by design" approach based on six principles: (i) cultivating a cybersecurity culture, (ii) adopting a cybersecurity life cycle for vehicle development, (iii) assessing security functions through testing phases, (iv) managing a security update policy, (v) providing incident response and recovery, and (vi) improving information-sharing among industry actors (ACEA, 2017). The document provides some specific recommendations and best practices to implement these principles when designing cybersecurity solutions for CASE vehicles. Ultimately, CASE vehicle cybersecurity protocols will need to be compatible across different vehicles and platforms, and solutions will have to be scalable across potentially millions of cars. Moreover, governments, OEMs, CASE vehicle service providers, and other stakeholders will need to collaborate in order to identify CASE vehicle cybersecurity risks and migration strategies (TRBOT, 2020).

5.4.2 Cybersecurity Legislation and Regulation

There is limited legislation or regulation on CASE vehicle cybersecurity in Canada and internationally

Transport Canada is developing principles and best practices for CASE vehicle cybersecurity (TC, 2019f). In addition, the federal government has provided general guidance on cybersecurity issues via Canada's *National Cyber Security Strategy* (PSC, 2018), although the strategy does not specifically address cybersecurity for CASE vehicles or in transportation systems. Two of Canada's international trade agreements, CPTPP and CUSMA, require that countries recognize the importance of building cybersecurity capacities and strengthening collaboration and cooperation in identifying and mitigating cybersecurity threats. However, neither agreement imposes any specific requirements (GC, 2016, 2018a).

In 2015, United States automakers, vehicles suppliers, and commercial fleet companies established the Automotive Information Sharing and Analysis Center (Auto-ISAC), an industry-driven community to share information about vehicle cybersecurity threats, vulnerabilities, and best practices (Auto-ISAC, 2019). Auto-ISAC was modelled on the Aviation Information Sharing and Analysis Center (A-ISAC), which has successfully played a similar role in addressing cybersecurity threats in the aviation industry (Kennedy, 2017). In 2016, the U.S. National Highway Traffic Safety Administration (NHTSA) released a guidance document, *Cybersecurity Best Practices for Modern Vehicles*. The document recommends systematic processes for identifying risks and analyzing potential threats, advocates for "explicit considerations to privacy and cybersecurity risks through the entire life-cycle of the vehicle," and provides a number of technical recommendations (NHTSA, 2016b). The NHTSA has indicated that it will request that CASE vehicle manufacturers provide reports on their compliance with this guidance, although such reporting will not be mandatory (NHTSA, 2016a). In 2017, the *Security and Privacy in Your Car Study Act* was introduced in the United States Congress. This Act would require the NHTSA to introduce regulations around vehicle cybersecurity and privacy (USC, 2017). If enacted, the law would require critical and noncritical systems in CASE vehicles to be segregated, introduce security requirements around data transmission and storage, require manufacturers to do cybersecurity penetration testing for CASE vehicles, introduce reporting requirements for hacking attempts, and more (Lim & Taeihagh, 2018; Taeihagh & Lim, 2019). Several states have legislation around cybersecurity in CASE vehicles, including California, Massachusetts, and Pennsylvania (Lim & Taeihagh, 2018).

5.5 Summary

CASE vehicle technologies generate and collect an enormous variety and volume of data that could present significant benefits to Canada, allowing for improved safety, efficiency, and accessibility in the transportation system. CASE vehicle data also offer opportunities for the private sector to provide new services, develop new business models, and identify new or increased revenue streams. Serious privacy risks are associated with the data generated and collected by CASE vehicles. Current laws and regulations lag behind technological advancements in data collection and analysis, and major unresolved issues surround the ownership of and access to these data, which may be held by a wide variety of actors, including multinational corporations and foreign governments. CASE vehicles also raise unique cybersecurity risks. Vehicles controlled or disabled by cyberattacks could endanger public safety or cause serious disruption to traffic and transportation systems. Addressing these complex issues will require coordination between multiple levels of government in different jurisdictions, as well as key stakeholders in the CASE vehicle ecosystem. In order to realize the benefits and opportunities associated with CASE vehicle data, it will be necessary to establish technical and legal standards around their use, storage, and transmission. Moreover, international coordination will be useful in resolving challenges around cross-border data flows and compatibility with data protection and privacy laws in different jurisdictions.

6

Mobility Planning

Chapter Findings

- The introduction of CASE vehicles could disrupt existing mobility choices, potentially reducing the need for personal vehicle ownership and either complementing or competing with public transit and active transportation (i.e., walking, cycling). CASE vehicles are also likely to have a major role in the movement of goods, both for long haul and cross-border freight and for delivery services in urban areas.
- The emergence of CASE vehicles is likely to have long-term impacts on urban planning, traffic operations, and municipal revenues and costs. Transportation and land use policy today will determine the future impact of CASE vehicles on urban sprawl, congestion, parking, and transportation infrastructure.
- A proactive and coordinated approach to planning and policy development across multiple levels of government will be necessary in order to achieve the potential mobility benefits of CASE vehicles.
- The uptake of CASE vehicles will likely require substantial investments to update existing transportation infrastructure for V2I connectivity. It is unclear who would be responsible for this infrastructure and cover its costs.
- CASE vehicles could make personal transportation more accessible and equitable, and offer benefits to older adults, children and youth, people with disabilities, and people with low socioeconomic status. However, CASE vehicles could also reduce transportation equity for these groups if they are not financially accessible or if they reduce public transit service.

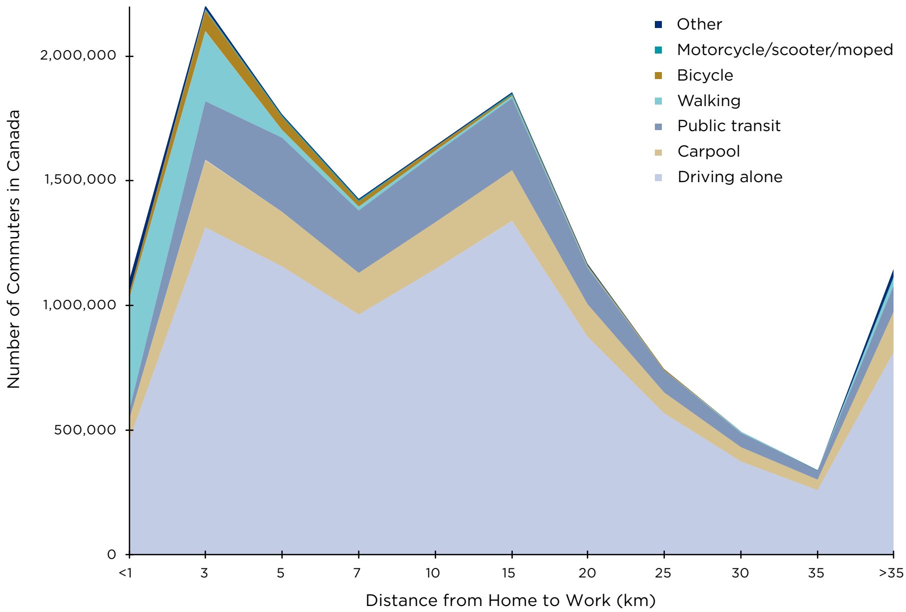
Transportation, mobility, and land use are interconnected (Heinrichs, 2016; Fraedrich *et al.*, 2019). The rise of the private automobile in the second half of the 20th century affected people's mobility and transportation choices; in response, city planning prioritized roads and car travel, furthering the use of the privately owned vehicle (Glaeser, 2011). CASE vehicles are expected to bring changes to the mobility and transportation choices of Canadians, and to urban form and transportation infrastructure, through an interplay between urban and transportation planning and how people choose to live, work, and move around. This chapter examines the potential impacts of CASE vehicles on the modes of transportation used, transportation policy and urban planning, and related accessibility and equity issues.

6.1 Personal Mobility

The introduction of CASE vehicles as a transportation option could disrupt current mobility trends in Canada. Personally owned vehicles are the main form of transportation for the vast majority of people in Canada today. In many cities, public transit and active transportation (walking and biking) play important roles in personal mobility. The rise of shared mobility services — such as ride hailing and micromobility — has disrupted the transportation sector and increased mobility choices for some people in Canada (Section 2.3). Shared mobility options are expected to grow in number and importance as CASE vehicles become more common and technologically advanced. In the future, integrated mobility solutions may bridge CASE vehicles, public transit, and active transportation into a single subscription service (i.e., MaaS).

Mobility in Canada is overwhelmingly based on personally owned vehicles

In 2017, Canadians made nearly 300 million trips using a personally owned or rented car or truck, compared to approximately 5.5 million trips by bus and 4.1 million trips by train (StatCan, n.d.). The majority of people in Canada (80% in 2016) use a personal vehicle to commute to and from work, regardless of distance (Figure 6.1). Of these commuters, 73.5% were living in a census metropolitan area (i.e., an area with a population over 100,000, with at least 50,000 living in the core) (StatCan, 2017c). Beyond commuting to and from work, the overwhelming majority of trips in Canada taken to visit friends and relatives or for pleasure or vacation are taken in a personally owned or rented vehicle (StatCan, n.d.).



Data source: StatCan (2019a)

Figure 6.1 Main Modes of Commuting by Distance from Home to Work in Canada

People in Canada commute to and from work mostly by driving alone in a personal vehicle regardless of distance, though about half of commuters who live less than a kilometre from work use active transportation regularly (e.g., walking and biking).

NB: The census assumes that the commute to work originates from the usual place of residence, but this may not always be the case. Sometimes, respondents may be on a business trip and may have reported their place of work or main mode of commuting based on where they were working during the trip. Some individuals maintain a residence close to work and commute to their home on weekends. Students often work after school at a location near their school. As a result, the data may show unusual commutes or unusual main modes of commuting (StatCan, 2019a).

The reliance on personal vehicle ownership in Canada reflects the flexibility and independence benefits of personal vehicles, which offer self-scheduled mobility and freedom to access more social and economic opportunities than those available through other modes of transportation (Olateju *et al.*, 2019). Decades of land use built around the automobile (e.g., suburbs and controlled-access highways) also contribute to the need for a personal vehicle, which, in turn, can result in a lack, or inadequacy, of infrastructure supporting alternative modes of transportation, such as public transit, walking, and cycling (Anowar *et al.*, 2016). For many people living in suburban, rural, and remote areas, a personal vehicle is often a requirement for accessing basic necessities such as grocery stores, healthcare, education, and employment, leading to higher rates of household vehicle ownership in rural areas (95%) compared to urban areas (79%) (StatCan, 2018b).

6.1.1 Implications of CASE Vehicles for Personal Mobility

Access to on-demand, affordable CASE vehicles could reduce personal vehicle ownership

Eighty-four percent of households in Canada owned or leased a vehicle in 2017 (StatCan, 2018b). However, approximately half of all Canadians would not own a car if they did not have to (Vision Mobility, 2019). This sentiment is much higher in urban areas (~55%) than in rural ones (~35%) (Vision Mobility, 2019). Although rates of car ownership in large cities in the United States have continued to increase since the introduction of ride hailing (Schaller, 2018), studies have found reductions in personal vehicle ownership correlated with the use of car sharing (Martin *et al.*, 2010) and ride-hailing services (Clewlow & Mishra, 2017a; Vision Mobility, 2019; Ward *et al.*, 2019; Sabouri *et al.*, 2020). Studies modelling CASE vehicle fleet operations have found that each shared autonomous vehicle could replace 4 to 11 conventional, privately owned vehicles (e.g., Fagnant & Kockelman, 2014; Boesch *et al.*, 2016; Gurumurthy & Kockelman, 2018). However, the predictions of reduced vehicle ownership resulting from CASE vehicles could be overly optimistic; for example, in at least some countries, ride hailing and micromobility tend to replace public transit more than replacing personally owned cars (Vision Mobility, 2019). Furthermore, current use of shared mobility services may not be a good predictor of future use, as many current business models in the industry are not profitable, and rely on investor support to subsidize the costs of the service (Olateju *et al.*, 2019).

Even with the introduction of SAE Level 4 and 5 vehicles in Canada, autonomous shared mobility services will likely be limited to population centres with sufficient density to support such services (i.e., greater than 400 people per square kilometre; see Section 2.3). Personal vehicle ownership may remain the norm in less densely populated and rural areas, with access to autonomous vehicles available only to those able to afford to personally own one, and limited by high purchase costs, at least early on in their availability. Moreover, even as shared mobility services expand in urban areas, any trend toward decreased individual ownership will likely take several decades, due in part to the relatively long turnover rate of vehicle ownership (approximately 20 years to replace 90% of current vehicles on the road in the United States (Keith *et al.*, 2019)).

CASE vehicles have mixed implications for active transportation

Active transportation primarily refers to walking and cycling for transportation (Stappers *et al.*, 2018), though it can include any means of "using your own power to get from one place to another," including wheelchairs (GC, 2014). In 2016, approximately 7% of commuters in Canada walked or cycled to and from work (StatCan, 2017c). While the impact of CASE vehicles on active transportation is an area of uncertainty, most available research suggests that CASE vehicles will decrease levels of active transportation (Spence *et al.*, 2020). If CASE vehicles emerge as a convenient and affordable transportation option, people may choose to use them instead of walking or cycling (Cavoli *et al.*, 2017). By replacing conventional transportation infrastructure and street design with wider sidewalks and bike lanes as part of urban planning for CASE vehicles, cities could become more pedestrian- and bike- friendly, and the level of active transportation could increase (Schwartz, 2018). However, decisions to invest in infrastructure to support active transportation are largely independent of whether vehicles are CASE or conventional (Botello *et al.*, 2018).

CASE vehicles will broaden shared mobility service offerings

Traditional forms of shared mobility such as taxis and rental cars have declined over the past several years, while the use of ride-hailing services has significantly increased (Vision Mobility, 2019). It is widely expected that the use of new shared mobility services will continue to grow (both in their number of users and in distance travelled) and that CASE vehicles will provide individuals with even more options for shared mobility, such as robo-taxis and autonomous shuttles (Botello *et al.*, 2018). The introduction of CASE vehicles could accelerate the trend of shared mobility services transforming the personal mobility marketplace from one based on buying vehicles to one based on buying rides. However, like current shared mobility service options, robo-taxis and autonomous shuttles are likely to be geographically limited to dense urban centres and boutique communities, and not available in most smaller cities, towns, and rural areas in Canada.

Furthermore, there have been concerns that despite their increasing popularity and market share, some important parts of the current shared mobility services industry (such as ride hailing) are skewed by an unsustainable reliance on investors for short-term viability, evidenced by the inability of many of these companies to turn a profit (Sherman, 2017). It is unclear how fares could be affected if investors in these companies eventually demand a return on their investment (Schaller, 2018). This represents an area of uncertainty in predicting the long-term adoption and sustainability of current as well as future shared mobility models based on CASE vehicles. Furthermore, this uncertainty creates a risk to municipal transit authorities, which may seek to develop partnerships with shared mobility service providers as part of integrated mobility systems (Olateju *et al.*, 2019).

CASE vehicles may affect the value of travel time saved

One factor in decision-making around travel modes is the time cost of travel, known as the *value of travel time saved* (VTTS); higher VTTS corresponds to higher time costs of travel (Wadud & Huda, 2019). As fully autonomous vehicles will allow users to engage in activities other than driving, they are generally expected to lower VTTS (Steck *et al.*, 2018; Wadud & Huda, 2019). However, evidence on perception of VTTS for CASE vehicles is mixed. Steck *et al.* (2018) found that compared to manual driving, VTTS was perceived to be lower for both personally owned (-31%) and shared (-10%) autonomous vehicles. Other studies have found that VTTS for CASE vehicles was perceived to be higher than both manual driving and traditional ride hailing (Gao *et al.*, 2019). This counterintuitive result may be due to respondents' lack of familiarity with driverless vehicles and hesitancy about an unproven technology, as the VTTS for CASE vehicles was significantly lower than both manual driving and traditional ride hailing when questioners explicitly mentioned the ability to multitask as a potential benefit (Gao *et al.*, 2019). Furthermore, perceptions of VTTS depend on in-vehicle activities. For example, VTTS for CASE vehicles is perceived to be lower than conventional vehicles if people worked instead of driving, but higher than conventional vehicles if people engaged in leisure activities instead of driving (de Looff *et al.*, 2018; Correia *et al.*, 2019). This could suggest that CASE vehicles may be more likely to replace other modes of transportation (e.g., manual driving, public transit) for work-related trips as opposed to leisure activities. However, it should be noted that these studies are speculative, recording perceptions for a product not yet available. Thus, the impact of CASE vehicles on VTTS is currently an area of uncertainty, and may change as consumers become accustomed to travelling in driverless vehicles.

6.1.2 Implications of CASE Vehicles for Public Transit

Public transit systems in Canada carried approximately 2.1 billion passengers in 2017, a 2.5% increase over the previous year (TC, 2019a). With increasing populations in cities, and with greater public transit efficiency and expanded services and hours, the overall use of public transit in Canada has increased over the past several decades. Approximately 12% of commuters in Canada regularly use public transit, with the highest proportion in Toronto (24%), Montréal (22%), and Vancouver (20%) (StatCan, 2017c).

Policy and investment decisions today will determine the future impact of CASE vehicles on public transit

The full impact of CASE vehicles on public transit is not yet clear. They could compete with public transit if they provide a more efficient, convenient, and cost-effective option for commuters, though an increase in shared mobility service providers could also increase the number of vehicles on the road and worsen congestion (Ticoll, 2015; Olateju *et al.*, 2019). Alternatively, CASE vehicles could complement or enhance public transit systems, increasing their flexibility and level of service (Ticoll, 2015; UITP, 2017; NACTO, 2019). For example, shared autonomous shuttles could help address the first/last mile problem, bringing people from home to the closest terminal stop of a rapid transit system (light rail, subway, or bus line), and from transit stations to their final destination (UITP, 2017). This could prove particularly helpful in providing access to public transit for people living in suburban and rural areas who are not close to transit stations, thereby encouraging ridership on public transit (UITP, 2017). However, if the introduction of CASE vehicles increases urban sprawl, the first/last mile problem could be exacerbated, as homes would be farther still from transit stops, resulting in commuters using CASE vehicles exclusively and bypassing public transit altogether.

Some research has suggested that a fleet of CASE vehicles could entirely replace traditional public transit in certain small- and medium-sized cities (OECD/ITF, 2015). In 2017, the town of Innisfil, Ontario, entered into a partnership with Uber in which it subsidized the cost of using the ride-hailing service in lieu of developing a traditional public transit system (Town of Innisfil, 2019). However, costs have become higher than anticipated, due to higher than expected levels of ridership (Town of Innisfil, 2019). In contrast, while traditional public transit has higher fixed costs, net costs typically decrease as ridership increases (McGrath, 2019).

Evidence regarding the impact of shared mobility services such as car sharing and ride hailing on public transit usage is mixed. The impact appears to be relatively small, and is highly variable depending on factors such as city size, demographics, and type of public transit. Some studies have found that the introduction of shared mobility services may slightly increase transit ridership (e.g., Hall *et al.*, 2018), while other studies have found that it may slightly decrease transit ridership (e.g., Clewlow & Mishra, 2017b), and yet other studies have found no significant link between shared mobility and transit ridership (e.g., Boisjoly *et al.*, 2018; Feigon & Murphy, 2018). Shared mobility services are more likely to have a complementary effect on public transit in denser, more walkable areas, and a negative impact on public transit usage in sparser and less walkable areas (Olateju *et al.*, 2019). Furthermore, the limited impact of ride hailing on public transit usage may be because ride hailing tends to be used more on an occasional basis, whereas public transit is used more for daily commuting (Feigon & Murphy, 2018).

Integrated mobility systems are also referred to as Mobility-as-a-Service. They link a variety of mobility options (e.g., public transit, active transportation, and shared mobility services) into a single system.

CASE vehicle technology also offers an opportunity for the automation of public transit itself, which could increase the affordability, efficiency, and reliability of these systems. Automation could reduce operating costs by eliminating the labour costs associated with drivers (CUTA, 2017; Tirachini & Antoniou, 2020); however, these potential job losses could slow the trend towards automation (Olateju *et al.*, 2019). For the automation of public transit to lower fares, operating costs would have to be reduced by more than 50% (Tirachini & Antoniou, 2020). The automation of public transit could also lead to more frequent service (OECD/ITF, 2015; Olateju *et al.*, 2019), which could allow for the use of smaller vehicles, deployed in such a way so as to keep total transport capacity roughly constant (Tirachini & Antoniou, 2020). However, public transit may only benefit from automation if it is prioritized, incentivized, and financially supported by multiple levels of government, as there is currently less investment in the automation of public transit than in the automation of private vehicles and shared mobility services (Sim *et al.*, 2019).

CASE vehicles create opportunities for integrated mobility systems

The rise of shared mobility services and the emergence of CASE vehicle technology presents an opportunity for public transit authorities to develop CASE vehicle-based integrated mobility systems (Kamargianni *et al.*, 2016; UITP, 2017; PM, 2018; Olateju *et al.*, 2019). Integrated mobility systems link several different mobility options (including public transit and shared mobility services), so individuals can select combinations of transportation options that best meets their needs (CUTA, 2017; UITP, 2017). Mobility systems are considered integrated to the extent that: (i) one ticket or smart card can be used to access a wide variety of mobility services, (ii) a single access portal is used for all modes of transportation, and (iii) they allow users to combine different mobility modes and services (Kamargianni *et al.*, 2016).

Integrated mobility systems involving CASE vehicles may be necessary in order to provide a practical alternative to private vehicle ownership (UITP, 2017). Integrated mobility options are provided through partnerships between transit agencies and private sector mobility service providers, and provide transit agencies with an opportunity to take on management roles in a larger mobility ecosystem (CUTA, 2017; UITP, 2017; Olateju *et al*., 2019). Several challenges arise in developing MaaS. For example, in at least some jurisdictions in Canada, government transportation officials believe that shared mobility services will not complement their public transit systems (Olateju *et al*., 2019). Additionally, "Canada's sparse population, non-homogenous regulatory environment, and varied transit funding formulas present challenges" to the adoption of integrated mobility systems across the country (Olateju *et al*., 2019). Data sharing between shared mobility service providers and transit authorities also presents challenges (Chapter 5).

The potentially conflicting goals and motivations of private-sector shared mobility providers and public-sector transit authorities may present additional challenges. While both aim to reduce reliance on personal vehicle use, shared mobility providers aim to create profit and maximize shareholder value, whereas public transit providers aim to make mobility services as widely accessible as possible, with financial costs offset by the broader economic and social benefits of the service (Olateju *et al*., 2019). These differing motivations are likely to create areas of tension. For example, public transit providers generally seek to increase occupancy rates in their vehicles in order to reduce fares, congestion, and emissions; by contrast, increased occupancy rates in shared mobility vehicles typically result in fewer trips and reduced revenue for providers (Olateju *et al*., 2019). Additionally, public transit agencies may be incentivized to not cooperate with other types of transportation providers because their funding is often linked to ridership numbers (Moore, 2017).

6.2 Transportation Policy and Urban Planning

Through their impact on mobility and transportation, CASE vehicles could have long-lasting impacts on the built environment. However, such changes are unlikely to be felt until the adoption of shared mobility and autonomous vehicle technology is substantial and widespread. The likely appearance of autonomous shuttles and robo-taxis on urban roads in the coming decades will have more immediate transportation policy and planning implications. Actions taken today to address urban planning issues such as congestion, curbside management, street design, and parking will affect the integration of CASE vehicles on city streets. Planning for infrastructure upgrades will need to consider the demand that such vehicles will place on elements such as connectivity and road maintenance. Over the longer term, the availability of CASE vehicles and their impact on mobility options for people in Canada may influence where and how people choose to live and work. While any such changes will likely not be visible in the next 10 years, municipal planning decisions and policies made today will be critical in determining how CASE vehicles first appear in different communities and how they are integrated into existing transportation systems (Faisal *et al.*, 2019; Overtoom *et al.*, 2020).

Planning for CASE vehicles requires coordination among multiple levels of government

Autonomous vehicles have the potential to be a "catalyst of urban transformation" (Duarte & Ratti, 2018) and many experts have argued for a proactive approach to transportation, urban, and infrastructure planning around them (e.g., Ticoll, 2015; UITP, 2017; NACTO, 2019). Since urban planning horizons are similar to the construction industry — about two decades — there is value in starting to consider the implications of CASE vehicles on urban and transportation planning. However, urban planners may not feel an immediate need to prepare cities for CASE vehicles. The Federation of Canadian Municipalities has indicated that, outside of Canada's largest cities, planning for CASE vehicles is currently a relatively low priority for most municipalities (J. Lawson, personal communication, 2019). A 2019 survey of transit and planning officials working in medium and large cities in Germany found that urban planners believe that issues such as traffic control, infrastructure, and urban planning for autonomous vehicles will become more important in the next 3 to 10 years (Fraedrich *et al.*, 2019). A lack of regulatory or policy imperative to spur urban planning for CASE vehicles may contribute to this lack of urgency on the issue.

CASE vehicles may be a lower priority for urban planners because it is not yet clear how the technology will develop and when (or if) it will become mature enough to warrant serious consideration (Fraedrich *et al.*, 2019). For example, in 2017 the Toronto Transit Commission released a report noting that the uncertainties around technology, cost, and timing prevented them from developing a strategic plan around CASE vehicles (TTC, 2017). Urban planners may also be skeptical about the ability of CASE vehicles to complement their existing transport and urban planning objectives. For example, some urban planners have indicated that personally owned autonomous vehicles will not benefit their objectives, and may actually conflict with them (e.g., by increasing existing problems such as sprawl and congestion) (Fraedrich *et al.*, 2019).

Conflicts may arise between different levels of government about the objective and priorities around planning for CASE vehicles. Municipal planners are more likely to be interested in using CASE vehicles to complement public transit and active transportation, whereas federal governments may be more interested in vehicle safety, energy efficiency, and supporting industry competitiveness (Fraedrich *et al.*, 2019). Surveys of city planners in the United States and Germany have identified concerns that urban planning priorities will not be compatible with federal and state policies and regulations for autonomous vehicles (Fraedrich *et al.*, 2019; NACTO, 2019). For example, state governments may mandate specific lanes for autonomous vehicles only, thereby potentially incentivizing private use at the expense of prioritizing public transit and active transportation (NACTO, 2019). City planners in the United States have expressed concerns that states may disallow municipalities from regulating private mobility companies or introducing curb management or congestion pricing, and other levels of government might introduce regulations, such as uniform infrastructure requirements, that would shift the focus of urban planning away from people and toward technological capabilities (NACTO, 2019).

6.2.1 CASE Vehicles and Traffic Congestion

The impact of CASE vehicles on traffic congestion is an area of uncertainty. While CASE vehicles may reduce congestion by decreasing personal vehicle use and increasing use of shared mobility services, they may also significantly increase the overall number of trips and vehicle kilometres travelled (VKT), thereby limiting the expected congestion reduction benefits (OECD/ITF, 2015; Litman, 2019). The use of ride-hailing services has been found to increase VKT (and thus congestion) in Toronto (City of Toronto, 2019b). However, CASE vehicles may also help to reduce congestion through improved traffic operations; V2V and V2I communication with other vehicles and infrastructure could allow for coordinated driving behaviour, smoother acceleration and braking, closer following distances, more efficient vehicle routing, and a reduction in collisions, leading to more efficient traffic flows (Anderson *et al.*, 2016; Narayanan *et al.*, 2020).

The implications of CASE vehicles for traffic congestion depend on geographic location

The introduction of CASE vehicles could increase congestion levels due to several factors, including induced travel demand (Narayanan *et al.*, 2020); new user groups (e.g., people with mobility-related disabilities or people who cannot obtain a driver's license) (Harper *et al.*, 2016); CASE vehicles driving empty (Fagnant & Kockelman, 2014; UITP, 2017; Narayanan *et al.*, 2020); and people choosing to live farther away from work and therefore needing to commute by a means other than public transit or active transportation (Carrese *et al.*, 2019). CASE vehicles may also contribute to congestion by driving more slowly and cautiously than human-driven vehicles (Mauracher & Lao, 2019), and frequent stops for pick-ups and drop-offs by CASE vehicles could further negatively affect traffic flows (Overtoom *et al.*, 2020). Furthermore, although CASE vehicles could increase road capacity, congestion tends to remain constant or even increase with increasing road capacity due to induced travel demand (Schneider, 2018).

The impact of CASE vehicles on congestion and traffic volume is unlikely to be distributed evenly throughout a city. Increases in traffic volume from CASE vehicles are more likely to occur on smaller local road networks because of pick-up and drop-off activity (OECD/ITF, 2015). Downtown cores may experience worse congestion as CASE vehicle trips are more likely to replace public transit trips in these areas, whereas suburban neighbourhoods may experience less congestion if ride sharing in CASE vehicles substitutes for the use of personal vehicles (WEF, 2018a). Due to smoother flows of traffic and reduction in bottlenecks and collisions, congestion reductions will likely be greater on highways than on arterial roads, since causes of delays on arterial roads (e.g., vehicles turning and the presence of pedestrians and cyclists) will still be present with CASE vehicles (Fagnant & Kocklman, 2015). However, Talebpour *et al.* (2017) found that when CASE vehicles are restricted to dedicated lanes on highways with ramps, congestion may significantly increase because of the lane-changing manoeuvres that CASE vehicles must undertake to enter the lane.

Ride sharing and public transit are important for decreasing traffic congestion

Several studies have found that while car-shared CASE vehicles (i.e., vehicles shared sequentially by single passengers) can increase congestion, ride-shared CASE vehicles (i.e., vehicles shared simultaneously by multiple passengers) can reduce congestion (reviewed in Narayanan *et al.*, 2020). However, ride-sharing services can also increase traffic, as they tend to pull users from active transportation modes (i.e., walking or cycling) more so than from personal vehicles (Schaller, 2018). Modelling by Naumov *et al.* (2020) found that without appropriate policy interventions to discourage automobile use (e.g., a VKT tax), CASE vehicle-based ride sharing may have the unintended consequence of taking ridership away from public transit, leading to higher levels of congestion. However, congestion may be significantly reduced when CASE vehicles are integrated with public transit systems (OECD/ITF, 2015; Ticoll, 2015; Salazar *et al.*, 2018). Without strong encouragement of ride sharing over single-occupancy rides, congestion problems are unlikely to be solved, and are likely to worsen, with autonomous vehicles (Schwartz, 2018; Sperling, 2018; Narayanan *et al.*, 2020).

6.2.2 CASE Vehicles and Street Design

The introduction of CASE vehicles is likely to have implications for street design. CASE vehicles could increase road capacity by allowing for closer following distances and smoother traffic flow, thereby potentially reducing the number of lanes needed on highways and city streets (Schlossberg *et al.*, 2018). Autonomous vehicles may also require less space between lanes for safety (Heinrichs, 2016; Schlossberg *et al.*, 2018). The space freed up by fewer and narrower lanes provides opportunities to introduce bike lanes, wider sidewalks, transit lanes, pick-up and drop-off zones for shared vehicles and public transit, or additional vehicle lanes, as well as the expansion of housing, school yards, parks, or community gardens (Schlossberg *et al.*, 2018).

However, the impact of CASE vehicles on road capacity will depend on the presence of V2V communication, the penetration rate of CASE vehicles, and the type of street or road (Narayanan *et al.*, 2020). At high levels of deployment, CASE vehicles could significantly increase road capacity; however, at lower penetration rates, CASE vehicles could actually decrease road capacity due to factors such as the interactions between CASE vehicles and conventional vehicles, and the likelihood that CASE vehicles will have gentler acceleration and deceleration profiles (reviewed in Narayanan *et al.*, 2020). The use of V2V for platooning of public transit and freight vehicles may also increase road capacity (Faisal *et al.*, 2019).

Like carpool lanes, CASE vehicles may be provided with dedicated lanes along busy highways or commuter routes (Fraedrich *et al.*, 2019; TRBOT, 2020). However, dedicated lanes for CASE vehicles may increase highway capacity only when penetration rates are at least 30 to 50%, depending on the highway type (Talebpour *et al.*, 2017). Furthermore, it has been suggested that priority lanes may be better suited for autonomous public transit vehicles due to concerns that autonomous vehicle-only lanes could incentivize personal vehicle use (NACTO, 2019). Dedicated lanes for autonomous low-speed shuttles and delivery vehicles transporting goods and people in core urban areas could protect them from the general flow of automobile traffic; lanes adjacent to the curb could allow for passenger pick-up and drop-off, with inner lanes reserved for through traffic (NACTO, 2019).

In addition, CASE vehicles are also likely to require changes to roadway infrastructure. CASE vehicles currently depend on their sensors to detect road markings for the purposes of centring themselves in a lane and detecting stopping points. However, road markings that are not clearly visible (due to lack of maintenance or weather conditions) pose problems for automated driving systems. Proposed solutions include high-contrast plastic road markings designed to be highly radar-reflective and easily machine-readable (currently being tested on

Ontario's Highway 407), as well as roadside or pavement-embedded sensors that communicate with CASE vehicles (AVIN, 2018; TRBOT, 2020).

CASE vehicles may dramatically reduce the need for parking infrastructure

CASE vehicles may require fewer parking spaces if they are able to drop off passengers then leave to pick up others. CASE vehicles could reduce parking demand by as much as 90%, depending on the ratio of ride-shared to single-occupancy trips and the presence or absence of high-capacity public transit (OECD/ITF, 2015; Rodier, 2018). Modelling suggests that an autonomous taxi service serving 5% of all existing trips in Atlanta, Georgia, could potentially reduce the number of parking spaces in core areas by 67% (Zhang *et al.*, 2017). The use of shared mobility services has already reduced demand for parking. For example, the introduction of ride hailing has caused demand for airport parking to decrease by about 6 to 7% in New York City (Wadud, 2020). CASE vehicles could also reduce the number of vehicles driving around looking for parking (Guerra & Morris, 2018), and V2I technology could direct vehicles to available spots after dropping off passengers (Fagnant & Kocklman, 2015). Alternatively, CASE vehicles could drive empty to avoid paying for parking, increasing traffic congestion and VKT (UITP, 2017; Rodier, 2018; Schwartz, 2018; Litman, 2019). As zero-occupancy vehicles may be inadvertently encouraged if parking availability is reduced too drastically in response to the introduction of CASE vehicles (Rodier, 2018), it will be important to develop parking policies that avoid such outcomes (Narayanan *et al.*, 2020).

With CASE vehicles, many existing parking lots and structures may become unnecessary, allowing them to be redeveloped (Ticoll, 2015; Henderson & Spencer, 2016). Parking garages that are well located, with good access to major transportation routes and a flexible layout, could be attractive to fleet operators for parking, charging, and maintaining their vehicles (Henderson & Spencer, 2016). Parking facilities could also be relocated to strategic hubs throughout a region rather than at or near businesses and homes (Nelson\Nygaard, 2018; Rodier, 2018). This could result in parking facilities being moved from dense urban areas to more peripheral areas of municipalities (CUTA, 2017). Modelling by Zhang *et al.* (2017) found that shared autonomous vehicles were more likely to park in areas adjacent to urban cores than on the city edge, presumably to better reach prospective passengers. The areas where they parked tended to be lower-income (and racialized) neighbourhoods where the land value was lower, which points to potential equity issues, but may also provide the areas with new opportunities for access to shared mobility services and the possibility of new infill developments (Zhang *et al.*, 2017).

Curbside management is increasingly important for CASE vehicles in urban spaces

Curb space use is changing and facing increasing pressures from ride hailing, online shopping deliveries, and on-demand food deliveries, which demand curbside space for seconds or minutes. Bike lanes, bus lanes, and bike and scooter parking also use this space (OECD/ITF, 2017a; Shaver, 2019). CASE vehicles will introduce new considerations to curbside management, with the need for pick-up and drop-off space likely to increase dramatically (OECD/ITF, 2017a), particularly during peak commuting hours and at mobility hubs that connect with other forms of transportation, such as light rail transit stations (Heinrichs, 2016). However, CASE vehicles require less curbside parking (NACTO, 2019), and will shift curbside management from being parking-focused to being focused on pick-ups and drop-offs (OECD/ITF, 2017a). The International Organization for Standards (ISO) recently accepted a proposal for a new ISO standard covering the operation of CASE vehicles and other similar devices at curbs and sidewalks (ISO TR4448) (Grush, 2020). The standard will define terminology and protocols for prioritizing, scheduling, and queueing autonomous vehicles and automated delivery vehicles dynamically, without the need for human oversight (Grush, 2020).

Curbside management strategies for CASE vehicles are already being developed in some jurisdictions. Washington, D.C., has tested various curbside management strategies, including real-time parking availability sensors, demand-based pricing, fees for using commercial loading zones, and restrictions on parking at certain times of the day (DC DDOT, n.d.). The City of Vancouver has introduced permits for services required for stopping at curbs to pick up and drop off passengers during daytime hours in the Metro Core Area (City of Vancouver, n.d.). The permit includes a 30-cent fee for each pick-up and drop-off, with fee reductions of 50% for zero-emission vehicles and no fees for accessible vehicles (City of Vancouver, n.d.). The now-cancelled Sidewalk Labs project in Toronto had proposed "dynamic curbs" that act as spots for loading and unloading passengers during high-traffic periods, and, in quieter times, act as active transportation infrastructure, community space, or freight loading zones, with pricing used to incentivize other modes of transportation and ride sharing (Sidewalk Labs, 2019).

CASE vehicles will influence urban sprawl and where people live

Shifting patterns in residential location choice is a long-term trend driven by a wide variety of demographic, social, and economic factors, and the potential influence of CASE vehicles on this trend is an area of uncertainty. Over the long term, the widespread adoption of CASE vehicles could impact urban sprawl by affecting where people choose to live (Faisal *et al.*, 2019). On-demand mobility without the constraint of a driver could lead to greater decentralization (i.e., urban sprawl) and specialization of neighbourhoods (Anderson *et al.*, 2014; Milakis *et al.*, 2018; Carrese *et al.*, 2019). Canada could see the growth of more edge cities — where businesses and retail locations spring up in previously rural or residential areas with good road access and blocks of available land — if the time cost of transportation to and from such places is reduced by CASE vehicles. Alternatively, CASE vehicles could also be an opportunity for urban centres to become more attractive and cost-effective places to live, with more economic, cultural, and social options for participation (Duarte & Ratti, 2018). Cities could become more pedestrian- and bike-friendly if conventional automobile infrastructure — such as parking lots, wide roads, gas stations, and service centres — is replaced with people-focused infrastructure, such as walkways, gardens, parks, and bike lanes (Schwartz, 2018). However, urban space must be proactively managed to achieve these benefits (OECD/ITF, 2015). Ultimately, the impact of autonomous vehicles on urban sprawl will likely depend on whether such vehicles are shared. According to modelling by Thakur *et al.* (2016), the introduction of privately owned autonomous vehicles is likely to reduce populations in inner and middle suburbs, and increase populations in outer suburbs. However, if shared autonomous vehicles become the dominant form of transportation, populations are likely to increase in the inner and middle suburbs, and decrease in the outer suburbs (Thakur *et al.*, 2016).

CASE vehicles could either enhance transit-oriented developments — dense, mixed-used, pedestrian-oriented urban development specifically designed to be walking distance from transit hubs (Renne & Appleyard, 2019) — by extending the accessible service area from 400–800 m to 2–5 km (Lu *et al.*, 2017), or halt such developments by reducing the need for commuters to use public transit (Conerly, 2016). KPMG (2017b) describes the impact of autonomous vehicles on urban form as creating *islands of autonomy*, "bounded concentrations of populations in places that range from college towns to cities-within-cities" that are economically and socially linked to surrounding areas. These islands are predicted to be the first places CASE vehicles will emerge and become prevalent, due to the local technology infrastructure and transportation network density. Islands will exhibit a range of characteristics depending on the type(s) of typical travel patterns, requiring different approaches to urban planning and design. In short, the CASE vehicle transportation system is not "one size fits all" and strategies for integration will likely reflect different community transportation needs (KPMG, 2017b).

6.2.3 Infrastructure Requirements for CASE Vehicles

CASE vehicles will likely require provinces and municipalities to make substantial infrastructure investments and increase infrastructure maintenance. Many jurisdictions, both inside and outside of Canada, are beginning to invest in preparing their infrastructure for CASE vehicles. The KPMG *Autonomous Vehicle Readiness Index* ranks Canada 13th (of 30) in infrastructure, well behind many comparable jurisdictions (KPMG, 2020a). This ranking is due in part to Canada's geographic size, its scarcity of electric vehicle charging stations, and its remote and rural areas, where technology infrastructure, network coverage, and road quality can suffer. These types of infrastructure problems present a challenge to the adoption of CASE vehicles in Canada. However, Canada is a top performer in industry partnerships (KPMG, 2020a), and the federal government has begun to invest in a range of relevant infrastructure through its *Investing in Canada* infrastructure plan (GC, 2018c) and *Smart Cities Challenge* (IC, 2019).

The type and extent of V2I required for CASE vehicles is uncertain

The extent to which new infrastructure is required for CASE vehicles is not yet clear (Grush & Niles, 2018). Some experts note that autonomous vehicles are currently being designed to work with no new infrastructure requirements (SSCTC, 2018), while others argue that V2I-enabled infrastructure will make CASE vehicles safer and allow them to offer a wider variety of services (AVIN, 2018). Most stakeholders agree that infrastructure investments will be necessary in order to maximize the potential benefits of CASE vehicles (SSCTC, 2018). Moreover, the question is not *whether* new infrastructure investments will occur, but rather, *when*. Some experts point out that the design and development of current infrastructure projects should include consideration of CASE vehicles, as any newly built infrastructure could quickly become obsolete if it is not built with CASE vehicles in mind (SSCTC, 2018); however, planning for such infrastructure will be difficult until it becomes clear what type of development path the technology will follow (Grush & Niles, 2018).

Infrastructure to enable V2I communications may require substantial investments

The size of V2I investments for enabling CASE vehicles are difficult to estimate, as they depend on the type of communications technology (i.e., DSRC or 5G), scale of deployment (e.g., changes to the TransCanada Highway vs. a small downtown core) and geographical location (e.g., cities, highways, or rural areas). Nevertheless, the high initial costs of deployment of V2I infrastructure may be a barrier to implementation (Steadman & Huntsman, 2018). Moreover, as evidenced by the United States, it is unclear who would be responsible for covering the costs of this infrastructure (Anderson *et al.*, 2016; Steadman & Huntsman, 2018). Municipalities and regional authorities that are already struggling to maintain existing transportation infrastructure could face considerable costs related to constructing or upgrading infrastructure for CASE vehicles (Grush & Niles, 2018). Ultimately, the deployment of V2I is likely to require both substantial public-sector investments and public-private partnerships (Steadman & Huntsman, 2018).

CASE vehicles will affect costs and revenues for multiple levels of government

Responsibility for transportation infrastructure, programs, and services is shared between all three levels of government in Canada; however, provincial and territorial governments accounted for approximately 90% of all government expenditures on road transportation and transit in 2016 (TC, 2018b). Road transportation makes up the vast majority of both federal (78%) and provincial and territorial (94%) transportation-related revenues (TC, 2018b). CASE vehicles are likely to create new cost considerations for various levels of government, which could affect public services. For instance, CASE vehicles will likely result in reduced municipal revenues from parking tickets and traffic violations (Anderson *et al.*, 2014; Mares *et al.*, 2018). Toronto generates around $100 million per year in net revenues from parking and traffic violations, amounting to about 1% of the city's total budget (Ticoll, 2015). Other levels of government will need to cope with reduced vehicle-related revenues from federal and provincial taxes on gasoline, automobiles and automotive parts sales, insurance, automotive services, and fees for driver and vehicle registrations and inspections (Ticoll, 2015). CASE vehicles could affect municipal revenues and costs related to public transit through their potential impacts on ridership and operating costs (Anderson *et al.*, 2014; CUTA, 2017; Tirachini & Antoniou, 2020). CASE vehicles may also increase the need for, and therefore the cost of, road maintenance if they increase overall VKT (Mares *et al.*, 2018).

However, CASE vehicles may also present opportunities for new sources of revenue for cities, such as pay-per-kilometre fees (i.e., VKT tax), curb space pricing, variable congestion pricing, and zero-occupancy taxes. CASE vehicles may also reduce some types of municipal costs, such as policing, and the automation of other public services, such as garbage collection, snow removal, and street cleaning, could also result in eventual cost savings for municipalities, assuming that these services could one day be automated (Ticoll, 2015). Furthermore, if the automation of public transit results in fewer collisions, costs related to insurance could be substantially reduced (Lutin, 2018).

6.3 Transportation Accessibility and Equity

The ability of people in Canada to move between locations — including the mode, the cost, and the time it takes — has significance for employment opportunities, health, and quality of life. Indeed, equitable access to transportation is an issue of human rights. One indicator for the United Nations Sustainable Development Goals is the "proportion of population that has convenient access to public transport, by sex, age and persons with disabilities" (UN, n.d.). Better access to transportation is associated with increased social inclusion (Spinney *et al.*, 2009) and greater overall well-being (Vella-Brodrick & Stanley, 2013). CASE vehicles present an opportunity to increase accessibility and equity in transportation by providing more mobility options to individuals and groups with limited access. The use of mobility data will be crucial to achieving these policy objectives (Chapter 5), and realizing these benefits will depend on how such vehicles are deployed and regulated.

6.3.1 CASE Vehicles and Transportation Costs

In 2017, Canadian households spent an average of $12,707 on transportation (nearly 15% of total household expenditures), of which 90% was on private transportation (StatCan, 2018c). Data for the United States show that low-income families spend an even larger proportion (over 30%) of their income on transportation (Cohen & Shirazi, 2017). If CASE vehicles provide affordable and convenient mobility services, household spending on transportation for those who can access them may decline. The Conference Board of Canada estimated annual average savings of around $2,700 (in 2012 prices) for the average Canadian household (nearly 4% of the household budget) with a shared autonomous vehicle service (Godsmark *et al.*, 2015). Further cost savings may accrue from electrification, as electric vehicles have lower overall operating costs (CAA, 2019).

The high expected purchase price of autonomous vehicles (relative to conventional vehicles), particularly early on in their deployment, is anticipated to limit purchasing to those with higher incomes (Anderson *et al.*, 2014; Fagnant & Kocklman, 2015; Milakis *et al.*, 2017). This initial high upfront cost makes shared mobility with autonomous vehicles a more likely scenario (Botello *et al.*, 2018; Sperling, 2018). Wadud (2017) estimated that the total annual cost of ownership for an autonomous vehicle could be 17% to 58% higher than a conventional vehicle, depending on income bracket. That said, attempting to predict the future costs of technology that is largely still in a research or prototype stage of development is fraught with difficulties. The costs of autonomous vehicle technology could decrease dramatically over the next decade or two. Moreover, analyses of autonomous vehicle costs typically do not distinguish between various types of ownership models, such as outright ownership vs. leasing. Thus, the precise impact of autonomous vehicle cost on rates of ownership and shared mobility usage is uncertain.

CASE vehicles could help to improve transportation equity

CASE vehicles are expected to broaden transportation opportunities for groups currently not able to drive themselves (Acheampong *et al.*, 2018). Older adults, children and youth, people with physical and cognitive disabilities, people with low socioeconomic status, and individuals who are not able to obtain a driver's license are expected to experience improved transportation equity with CASE vehicles (Ticoll, 2015). Improved mobility could increase personal independence, social connection, and access to essential services (Anderson *et al.*, 2014). CASE vehicles may also eliminate first/last mile problems for people with disabilities and older adults (Acheampong *et al.*, 2018).

Many experts emphasize that extending the potential benefits of CASE vehicles to everyone will require some form of government response, through regulation, incentives, research, or targeted programs and services (Cohen & Shirazi, 2017; Pakusch *et al.*, 2018; Sim *et al.*, 2019). Just as governments intervened to bring electricity to rural areas and make telephones more affordable, access to CASE vehicles may require similar equity-based interventions for those in rural areas, as well as those limited by cost (Cohen & Shirazi, 2017). Indeed, the profitability goals of private-sector automakers and mobility service providers may not align with the goal of creating equitable transportation systems, as what is most appealing economically does not necessarily prioritize social benefits (Sim *et al.*, 2019). Transit authorities will need to work with municipalities and shared mobility service providers to ensure equitable access to CASE vehicle-based mobility (Olateju *et al.*, 2019).

CASE vehicles could reduce mobility options for people living in poverty by competing with public transit

In the eight largest cities in Canada, 40% of low-income residents — nearly a million people in total — are at risk of transport poverty, that is, "the compounded lack of ability to travel to important destinations and activities," which includes both transit and automobile access (Allen & Farber, 2019). Transit poverty disproportionately affects people centralized in densely populated, low-income, apartment-tower neighbourhoods that are not located on a main transit line, as well as low-income populations living in low-density suburban neighbourhoods (Allen & Farber, 2019). Poverty rates are increasing in older suburbs and in areas with high proportions of high-rise buildings outside of the urban core in Montréal, Vancouver, and Toronto (Ades *et al.*, 2016). Low-income residents of Toronto are less likely to own a vehicle than high-income ones, further limiting their access to social and economic opportunities (TRBOT, 2020). Moreover, low-income suburban families that do own a vehicle are also more sensitive to the increasing costs of ownership (such as higher interest rates on car payment loans or higher fuel costs), making this ownership unstable (Allen & Farber, 2019).

CASE vehicles could improve transportation equity for people with low income if they reduce the cost of transportation. However, if CASE vehicles compete with public transit, they could reduce transportation equity for these groups. Such an outcome could be avoided by subsidizing CASE vehicle trips to and from transit stations, or subsidizing the use of CASE vehicles only for households in areas with low transit access. Integrated mobility systems that employ multi-modal transportation hubs could improve access to transportation in low-income communities; however, the development of these platforms must ensure that households without bank accounts, credit cards, or means to access online payment can still participate (Cohen & Shirazi, 2017).

6.3.2 Mobility for People who do not Drive

Older adults could benefit from CASE vehicle technology

Older adults are a growing segment of the Canadian population (an estimated 17.2% in 2018 predicted to rise to 23% by 2030) (StatCan, 2019b). Access to transportation among older adults is associated with a higher quality of life (Spinney *et al.*, 2009); by contrast, cessation of driving is associated with adverse health outcomes and symptoms of depression (Chihuri *et al.*, 2016). Driving is the most common and preferred mode of transportation for older adults (Hassan *et al.*, 2019); however, older adults are more likely to avoid or limit their driving compared to other age groups (Crayton & Meier, 2017). Of people aged over 65, 25% do not have a driver's license (Godsmark *et al.*, 2015), compared with less than 10% of adults aged 35 to 44 (CIPMA, 2019). Other modes of transportation (walking, cycling, and public transit) can be difficult for older adults facing physical mobility issues and access to these modes may be limited, especially in rural areas (Hassan *et al.*, 2019). Older drivers are also involved in more collisions than younger drivers (Reimer, 2013), which CASE vehicles could substantially reduce.

The use of publicly available ADAS technology (SAE Level 1 and 2) may already benefit older adults by assisting in difficult driving conditions and improving driver confidence (Reimer, 2013). Furthermore, more advanced ADAS technology (Level 2 and 3) could be programmed to accommodate various levels of driver ability or disability (Deloitte, 2018a). However, the greatest benefits for older adults require Level 4 and 5 vehicles (Milakis *et al.*, 2017). Realizing the benefits of automated driving for older adults also requires consideration of the door-through-door transportation experience, as they may have difficulty booking services, navigating the curbside and boarding the vehicle, and may need room to store personal mobility devices (walkers, wheelchairs). In addition, older adults may be less accepting of automated driving technologies than younger adults (Hassan *et al.*, 2019).

Children could use CASE vehicles to access academic, extracurricular, healthcare, and social activities.

With the introduction of fully autonomous vehicles, a teenager could more easily get to after-school activities across the city independently. Parents would also benefit from no longer needing to chauffeur their children. However, there is high variation among parents regarding the age at which they believe a child should be allowed to use a CASE vehicle by themselves (Tremoulet *et al.*, 2018), as well as variation in the acceptability of a child travelling alone (Tremoulet *et al.*, 2018; Lee et al., 2020). Research has found that parents would be very reluctant to allow their children ride in an autonomous school bus compared to a conventional, human-driven school bus (Anania *et al.*, 2018). Additional parental concerns include the ability to remotely monitor and communicate with their child while in an autonomous vehicle, parental control over the vehicle's destination and ability to make stops, and the need for safety features such as seatbelt requirements and the ability to prevent intruders from entering the vehicle (Tremoulet *et al.*, 2018; Lee *et al.*, 2020). Education, and potentially licensing, will be needed to ensure minors know how to properly use CASE vehicles (e.g., safety devices, providing instructions about destination) and deal with unforeseen circumstances.

CASE vehicles could increase the personal freedom of people with disabilities

One in five people in Canada have one or more disabilities that limit daily activities (StatCan, 2018a). Of these, 4 in 10 have a "severe" or "very severe" disability, which is associated with lower rates of employment, lower income, and a greater likelihood of living in poverty (StatCan, 2018a). Autonomous vehicles could help improve accessibly for people with physical or sensory disabilities (Acheampong *et al.*, 2018; Milakis *et al.*, 2018), providing them with better access to employment opportunities, healthcare, and social interaction, thereby enhancing their well-being while also reducing the burden on caregivers (Claypool *et al.*, 2017). In addition, the use of CASE vehicles could improve public paratransit services, which are often much costlier than mainstream public transit (Anderson *et al.*, 2014; Lutin, 2018). For example, collaborating with ride-hailing services Uber and Lyft for paratransit trips has reduced overall costs in Boston by 20%, while allowing users to take 28% more trips (Bankson, 2017). In a survey of people with intellectual disabilities, some respondents expressed anxiety about using

CASE vehicles, particularly because of a perceived lack of control; however, they were also positive about using CASE vehicles to gain personal freedom and expressed less anxiety when they had prior knowledge of autonomous vehicles (Bennett *et al.*, 2019).

There will be challenges around ensuring equitable access to CASE vehicles for people with disabilities. Ride-hailing companies have struggled to provide equitable service, often providing uneven, inconsistent, and limited services, even with programs specifically designed for people with disabilities (Olateju *et al.*, 2019). In the United States, several lawsuits filed against ride-hailing providers allege discrimination against people with disabilities (Linder, 2019). Additional regulation and policy may be required in order to ensure equitable access to shared mobility services, as well as additional investment in paratransit services. While it is likely that autonomous and on-demand mobility may increase the costs of public paratransit services, it has been suggested that this could be offset through collecting fees from private shared mobility service providers that do not sufficiently accommodate people with disabilities (Olateju *et al.*, 2019).

Inclusive design will be essential to realizing the benefits of CASE vehicles

The functioning of CASE vehicle technology must be non-discriminatory and inclusive in order for all people to realize its benefits. For example, some individuals may find it difficult to enter and exit the vehicle, interact with the user interface to select a route or stop the car, and operate safety devices in the vehicle. Straightforward operation, simple user interfaces, and clear signage within the vehicle are important elements (Claypool *et al.*, 2017). People who do not own a smartphone, do not have a credit card, do not have access to the internet for online payment, are unable to use the required technology, or do not speak the language of the mobility system may be excluded from using shared mobility services (Cohen & Shirazi, 2017). People may also not be willing or able to use shared vehicle services if they wish to avoid situations of close confinement with strangers (Cohen & Hopkins, 2019). Discrimination is a problem with current ride-hailing services. For example, a study of ride hailing in Boston observed that “the cancellation rate for African American sounding names was more than twice as frequent compared to white sounding names” (Ge *et al.*, 2016). Shared mobility technology design must ensure that biases are not introduced into the software, creating discriminatory experiences for the user or wider community. For example, algorithms could route vehicles through areas or past businesses that pay to have their stops included in sightseeing itineraries (e.g., multinational corporations), neglecting smaller or locally owned businesses (Cohen & Hopkins, 2019).

6.3.3 CASE Vehicles in Rural and Remote Areas

In 2011, 18.9% of Canadians were living in rural areas (defined by Statistics Canada as having a population under 1,000) (StatCan, 2012b). In the Atlantic provinces and territories, this proportion is higher: rural populations are greater than 50% in Prince Edward Island and Nunavut (StatCan, 2012b). CASE vehicles could benefit inhabitants of rural and remote communities, by increasing their independence and facilitating economic growth and productivity (Cutean, 2017).

Delivering the benefits CASE vehicles to rural and remote communities will present challenges

Innovation in CASE vehicle technology is largely taking place in urban spaces (Cohen & Hopkins, 2019), and vehicle development does not necessarily take the realities of rural areas into account. Autonomous vehicles must be tested and developed in a diversity of weather conditions, geographical locations, and terrains to maximize their safe operation. Without interoperability across Canada, CASE vehicle-based mobility systems could contribute to inequities by favouring wealthy, urban communities, and leaving rural and vulnerable populations behind (Sim *et al.*, 2019). The shared use of rural roads (with farm equipment, horses and carriages, snowmobiles, ATVs, etc.), as well as the variation in road surfaces (e.g., unpaved, dirt, snow, ice) and quality of road maintenance, may create additional challenges for the safe operation autonomous vehicles in rural areas. As well, reliance on the commercial sector to deliver shared mobility services could leave rural areas behind, as private companies will not be able to provide services to areas that are not profitable (Sim *et al.*, 2019). Partnerships between shared mobility providers and rural organizations, such as municipalities, to bring mobility services to rural communities may help to ensure equitable service offerings (Olateju *et al.*, 2019). In addition, the introduction of long-haul autonomous bus services could improve accessibility for people in rural areas who cannot drive or afford a personal vehicle. If automated driving reduces the operating costs of bus service (for instance, by removing the cost of driver labour), previously discontinued bus routes could once again become economically viable.

6.4 Movement of Goods and Urban Freight

Commercial and industrial organizations are likely to be among the early adopters of CASE vehicle technology because they can both afford the high upfront capital costs of new technology, as well as potentially recoup those investments thanks to lower operational costs. Freight and delivery companies, for example, are likely to use CASE vehicles to facilitate the movement of goods both within and among cities.

CASE vehicles will likely facilitate the movement of goods in urban areas

CASE vehicles could improve the reliability and productivity of urban delivery services, as well as reduce costs associated with parking, labour, and fuel (Godsmark *et al.*, 2015; Ticoll, 2015). Autonomous delivery services may help to overcome last-mile delivery problems, that is, the difficulty associated with delivery of parcels from centralized distribution centres to individual consumers (Henderson & Spencer, 2016; Hoffman & Prause, 2018). Autonomous delivery services could affect how cities and other municipalities approach traffic and curbside management, as well as street parking and access for delivery services. Automation will likely influence delivery business models, increasing the breadth, variety, and volume of services available, though also contributing to a loss of driving jobs in this sector (Ticoll, 2015). However, people in Canada could see lower prices for consumer goods as freight costs decrease because of automation (Godsmark *et al.*, 2015; Ticoll, 2015).

Potential models for CASE vehicle-based delivery services include autonomous delivery vehicles with delivery persons responsible for logistics (but not driving) and autonomous delivery vehicles without delivery persons (where parcels are stored in a bank of lockers) (Joerss *et al.*, 2016). Fleets of small, slow-moving autonomous robots, not much larger than a regular parcel, that drive on sidewalks, or fleets of drones (autonomous aircraft) that are managed remotely are also potentially viable delivery models for CASE vehicle technology (Joerss *et al.*, 2016). Crowdsourced delivery services (i.e., an Uber-style model of delivery) may also play a role in urban freight, especially for new entrants to the market, as such business models can be quickly scaled up without major capital investments (Joerss *et al.*, 2016). Several crowdsourced delivery services, such as Amazon Flex, are already in operation in some jurisdictions in Canada (Amazon, 2020).

Joerss *et al.* (2016) predict that, by 2026, autonomous vehicles could deliver up to 80% of all parcels in average- and high-density urban areas, as well as some rural areas with low to average density. During non-delivery hours, these same vehicles could serve as stationary parcel lockers (Joerss *et al.*, 2016). Researchers are developing fully autonomous delivery vehicles that can pick up and deliver packages with a robotic arm and custom-made delivery boxes (e.g., Heinrich *et al.*, 2018). However, there are unresolved regulatory issues around the use of autonomous vehicles for urban freight delivery (Hoffman & Prause, 2018) and many countries (including Canada) lack regulation that can accommodate autonomous ground vehicles outside of testing or pilot projects (Joerss *et al.*, 2016). Some types of autonomous delivery vehicles raise many of the same liability issues as autonomous personal vehicles; however, autonomous parcel lockers and small sidewalk-driving robots, which are likely to fall under a different type of vehicle classification, have unique issues, such as shared use with pedestrians and different legal standings, depending on location (Hoffman & Prause, 2018). The adoption rate for autonomous delivery services will depend primarily on opportunity cost, regulation, and public acceptance (Joerss *et al.*, 2016).

CAT technology will likely be used for the long-distance movement of goods and cross-border freight

In 2016, trucks delivered 90% of freight shipments in Canada (StatCan, 2019d). Connected and autonomous trucks (CATs) could reduce costs, increase efficiency and productivity, reduce fuel consumption, increase safety, and reduce the environmental impact of long-haul trucking. CATs are likely to reduce the operating costs associated with long-haul trucking, the largest share of which are driver labour (32%) and fuel (25%) (Shankwitz, 2017). CATs could decrease fuel use by 10 to 15% through platooning (DHL, 2014; Clements & Kockelman, 2017), and removing driver working time restrictions could make vehicle use up to 43% more efficient (Godsmark *et al.*, 2015; Ticoll, 2015). Overall, CATs could reduce operating costs by up to 30%, depending on the level of automation (OECD/ITF, 2017b). These savings could help offset the higher costs of acquiring and repairing autonomous trucks relative to conventional heavy-duty trucks (Anderson *et al.*, 2018; Huang & Kockelman, 2020). Wadud (2017) found that the total annual cost of ownership of a CAT could be 15% lower than a conventional truck. Finally, the ability of CATs to work nearly 24 hours a day, and the consequent increased productivity, could result in lower per-kilometre freight delivery costs (Huang & Kockelman, 2020).

Use of SAE Level 1 or Level 2 automation in CATs could reduce collisions by using features such as lane centring and adaptive cruise control (Clements & Kockelman, 2017). At Levels 3 and 4, connected and autonomous technology could allow for CAT platooning. The most likely scenario for CATs may be "exit to exit" rather than "dock to dock" (Anderson *et al.*, 2018), meaning that CATs would move autonomously on controlled-access highways between transfer stations located near highway exits. At these transfer stations, human drivers would take manual control of the truck or the truck's cargo would be transferred to human-driven trucks to avoid the difficulty of CATs navigating city streets or manoeuvring to loading docks. In this scenario, the demand for first/last mile delivery drivers may offset some of the predicted job losses (Anderson *et al.*, 2018).

CATs are also likely to have an impact on cross-border trade between Canada and the United States, most of which is currently carried out by trucks (Roy, 2016). Modelling by Huang and Kockelman (2020) predicts that the introduction of CATs will increase total U.S. export flows, and increase international trade between the United States and Canada (as well as between the United States and Mexico). While CATs could reduce border crossing complications caused by the immigration status of drivers, the navigation of border crossings may be challenging for CATs due to the complex geography of crossings and inspection plazas. A dedicated staff of drivers at border crossing or inspection points may be needed in order to manually control trucks, as well as act as liaisons between importers and border officials (Anderson *et al.*, 2018). Significant regulatory and legislative changes are necessary in order to accommodate CATs at border crossings in Canada — for example, in policies and procedures for the reporting and control of commercial and regulated goods — and the lack of a driver may pose additional challenges when irregularities with electronic documents and shipments are detected. Moreover, any changes would have to be harmonized with regulations in the United States (Anderson *et al.*, 2018). If CATs are unable to cross borders, long-haul autonomous trucking may become available for domestic freight movements but not for cross-border movements. This could increase the cost of Canada-United States trade and negatively affect companies that are part of cross-border supply chains — a significant share of Canada's trade with the United States (Anderson *et al.*, 2018). The timeline for the rollout of CATs is unclear, with estimates ranging from 5 to 7 years (McKinsey, 2018b), to as long as 20 years (Simpson *et al.*, 2019). After reviewing several different estimates, Anderson *et al.* (2018) conclude that Canadian government agencies should prepare to accommodate a substantial number of CATs by 2030.

6.5 Summary

Mobility planning is likely to be dramatically affected by the introduction of CASE vehicles, just as the introduction of the private automobile shaped mobility planning in the 20th century. CASE vehicles are likely to affect personal mobility choices by offering a variety of new mobility modes to a broad range of user groups, thereby potentially reducing reliance on personal vehicle ownership in more densely populated areas, and helping to make personal transportation more accessible and equitable for individuals who currently have limited mobility options. However, realizing the potential benefits of CASE vehicles will require a proactive and coordinated approach to planning and policy development across multiple levels of government. Furthermore, the impacts of CASE vehicles on the transportation system will first appear in urban areas, and are unlikely to be widely available in most smaller cities, towns, and rural areas in Canada over the next decade. Nevertheless, CASE vehicles will have long-term impacts on urban planning, traffic operations, and transportation infrastructure, as well as affecting government revenues and costs. Autonomous vehicle technology is also likely to affect the movement of goods and freight both within and between cities, as well as across the Canada-United States border. Ultimately, planning and policy decisions made today will affect how, when, and where CASE vehicles are used in Canada in the coming decades.

7

Health and Well-Being

Chapter Findings

- Improvements to air quality and lower greenhouse gas emissions are achievable with 5% CASE vehicle diffusion, but mobility solutions that lower VKT (e.g., ride pooling, active transportation, public transit) are essential. Otherwise, the appearance of CASE vehicles on Canadian roads could result in lower air quality.
- ADAS technologies can improve road safety, and fully autonomous vehicles could further reduce injuries and fatalities by eliminating human error in driving, which is a factor in over 90% of collisions.
- Establishing robust safety standards for CASE vehicles will require significant efforts in the collection, pooling, and analysis of driving and collision data from both automated driving systems and human drivers. Regulators at all levels of government, as well as stakeholders from industry and the public, will be making decisions, either tacitly or actively, about acceptable levels of risk in the deployment of CASE vehicles.
- CASE vehicles can improve safety for other road users, such as pedestrians and cyclists. However, because of the problems with human attention and reengagement, SAE Level 3 vehicles may actually worsen road safety in the transition between automated and human drivers.
- CASE vehicles will decrease physical activity should trips in them replace trips that would otherwise have been made using active transportation (i.e., walking, biking).

While the impacts of CASE vehicles on health, safety, and the natural environment may not be felt for several decades, current policy and regulatory decisions on vehicle emissions, safety standards, and active transportation will directly affect the future health and well-being of Canadians, as well as Canada's natural environment. Achieving the societal benefits of CASE vehicles will depend on coordination and cooperation among different levels of government and among government, industry, and other stakeholders.

7.1 The Environment

The transportation sector is a major contributor to both GHGs and air pollution in Canada

Increases in the concentration of greenhouse gases (GHGs) in the atmosphere cause climate change (ECCC, 2020). The transportation sector has consistently been the second largest source of GHG emissions in Canada, after the oil and gas sector. Transportation accounted for 25% of Canada's total GHG emissions in 2018 (ECCC, 2020). Between 1990 and 2018, total emissions from passenger vehicles grew by 39% and emissions from freight trucks more than tripled. Road transportation (i.e., passenger cars, passenger light trucks, and freight trucks) accounted for approximately 83% of transportation-related GHG emissions in 2018 (ECCC, 2020).

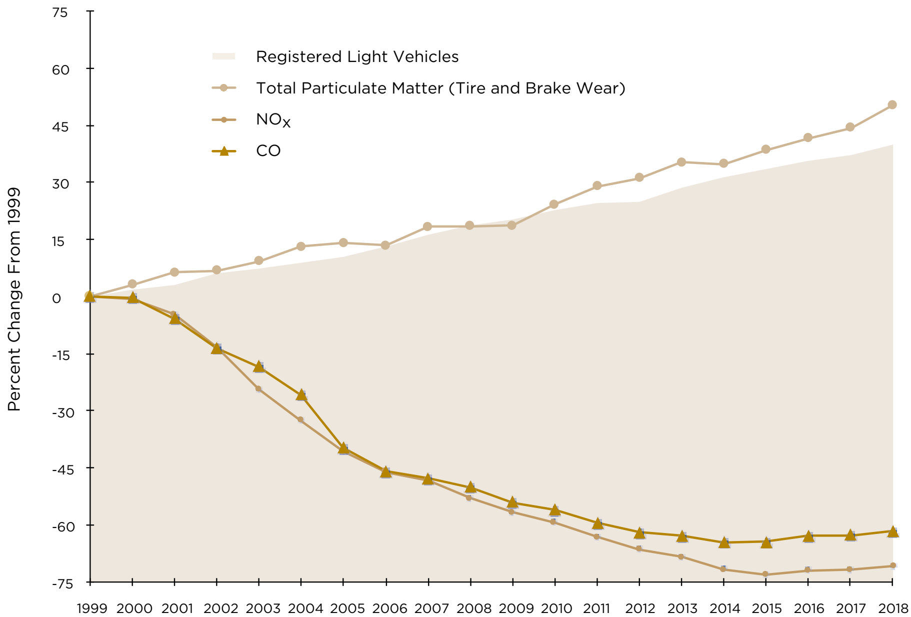
The transportation sector is also a substantial contributor to air pollution that can negatively impact human health (Box 7.1), and is responsible for over half of the measured carbon monoxide (CO) and nitrogen oxides (NO_x) in air quality samples (StatCan, 2012a). As well, dust from paved and unpaved roads and construction contributes substantially to the level of particulate matter in ambient air (StatCan, 2012a).

Box 7.1 Health Impacts of Pollution from Motor Vehicles

Motor vehicles release a number of pollutants harmful to human health: $PM_{2.5}$ and PM_{10}, as well as black carbon, ultrafine particles, nitrogen oxide, and carbon monoxide (Glazener & Khreis, 2019). $PM_{2.5}$ (particulate matter) is a particularly important risk factor for the environment and for human health (HC, 2017). $PM_{2.5}$ refers to solid particles and liquid droplets less than 2.5 micrometres (μm) wide. The main source of $PM_{2.5}$ is direct emissions from combustion (from motor vehicles, power generation, industrial facilities, residential fireplaces, and agricultural burning) (Gov. of ON, n.d.). $PM_{2.5}$ can also be formed by chemical reactions among gases such as sulphur dioxide and nitrogen oxides; the reduction of these precursor gases is therefore also important in reducing levels of $PM_{2.5}$ (Gov. of UK, n.d.).

Ambient air pollution increases the risk of cardiovascular disease, stroke, respiratory diseases, lung cancer, pneumonia, childhood asthma, chronic obstructive pulmonary disease, type 2 diabetes, and obesity, among others (Glazener & Khreis, 2019). Pollution from motor vehicles specifically is conservatively estimated to cause 1% of all air-pollution deaths worldwide — 184,000 deaths per year (Glazener & Khreis, 2019). Air pollution in Canada is low relative to other countries, but exposure to air pollution from human sources is still responsible for approximately 14,400 premature deaths per year (HC, 2017). The United States has a major impact on levels of air pollution in Canada; in Ontario, 50% of $PM_{2.5}$ comes from the United States. According to a 2012 estimate, transportation caused 22% of all $PM_{2.5}$ emitted in Ontario, with road vehicles responsible for 3% of all $PM_{2.5}$ emissions (Gov. of ON, n.d.).

While such vehicle emissions (CO and NO_x) have been declining over the past 10 years, total particulate matter (from light vehicles) has risen in tandem with the increase in the number of registered light vehicles in Canada (Figure 7.1).



Data source: StatCan (2019c), GC (2020)

Figure 7.1 Percent Change in Air Pollutants from Light Vehicle Emissions, 1999 to 2018

Nitrogen oxides (NO_X) and carbon monoxide (CO) levels have declined over the past 10 years, while the total particulate matter attributable to light vehicle emissions from tire and brake wear has risen in tandem with the increase in registered light vehicles (i.e., vehicles weighing less than 4,500 kg) in Canada. To illustrate the change in emissions annually, the percent difference from 1999 values is shown.

7.1.1 Predicted Impacts of CASE Vehicles on Emissions

The impact of CASE vehicles on vehicle emissions will largely depend on three factors: the influence of CASE vehicles on total VKT; the type of propulsion system used in CASE vehicles (which, as stated in Chapter 2, the Panel believes will be electric); and the influence of CASE vehicles on driver behaviour (e.g., acceleration, braking). Any impacts will also depend on the level of diffusion, that is, what proportion of vehicles on the road are autonomous, semi-autonomous, or human-driven. Thus, there is substantial variability among predictions of how CASE vehicles may affect the environment and it is reasonable to expect impacts will ultimately vary depending on local policies, driving cultures, changes in mobility behaviours (e.g., number of trips taken, cost per trip, adoption rates, and convenience), the proportion of EVs on roads regardless of automation, and government regulations, among others.

CASE vehicles could increase VKT

The one-to-one replacement of a conventional internal combustion engine (ICE) vehicle with an autonomous ICE vehicle has been estimated to lead to increases in VKT and GHG emissions, and lower public transit use, using a model of transportation behaviour for the Greater Toronto and Hamilton Area in Ontario (Wang *et al.*, 2018). The electrification of autonomous vehicles would lower GHG emissions from current values, though such reductions are dependent on the electricity source (Wang *et al.*, 2018).

The ability of a CASE vehicle to travel empty between fares, and to coordinate route efficiencies with other CASE vehicles, allows for the mobility needs of a population to be met with a smaller overall vehicle fleet compared to a fleet of personally owned vehicles (Burns *et al.*, 2012). Evidence from car-sharing programs in the United States indicates a reduction in both vehicle ownership rates and VKT among people who join the programs, leading to a commensurate reduction in GHG emissions (reviewed in Lazarus *et al.*, 2017). However, not all shared vehicles are alike. Mobility services such as ride hailing can lead to an increase in the total number of vehicles on the road (Vision Mobility, 2019). Moreover, the reduction in VKT from car-sharing programs appears to depend on how shared vehicles are used, with the replacement of primary vehicles leading to lower VKT, but higher VKT overall if the car share is in replacement of a secondary vehicle or public transit use (reviewed in Olateju *et al.*, 2019).

OECD/ITF (2015) found that even under the most optimistic scenarios, CASE vehicles are likely to increase VKT by as much as 90%, depending on the level of deployment (50% vs. 100%), the type of vehicle sharing (car sharing vs. ride sharing), and the presence or absence of high-capacity public transit. Fagnant and Kockelman (2014) predict that shared autonomous vehicles could increase overall travel distance by 11% as they travel empty to reach their next passenger. As well, Harper *et al.* (2016) estimate that the addition of new user groups for CASE vehicles (i.e., people who do not currently drive) could increase total VKT in the United States by 14%. However, ride sharing (i.e., having more than one person in a vehicle, see Box 2.2) can decrease trips — according to one estimate, a taxi service in which passengers share rides can reduce total taxi trips by up to 40% (Santi *et al.*, 2014). Several studies (e.g., Fagnant & Kockelman, 2014; Fagnant *et al.*, 2015; Zhang *et al.*, 2015) find that CASE vehicles could help reduce emissions even with an increase in vehicle use and VKT, due in part to fewer cold starts. The introduction of pricing policies or regulations may be required to encourage the uptake of ride sharing (Rodier, 2018). Indeed, some argue that without strong incentives for ride sharing, congestion problems are unlikely to be solved, and more likely to worsen, with CASE vehicles (Schwartz, 2018; Sperling, 2018).

CASE vehicles could allow for smoother traffic flow

Another presumption with CASE vehicles is that they will improve traffic and congestion by allowing for tighter following distances (e.g., platooning), smoother traffic flow (less stop-and-go), and greater network control (e.g., intersection management, variable speed limits). In a review of the literature modelling the impacts of CASE vehicles on traffic, Narayanan *et al.* (2020) found that impacts vary depending on the level of diffusion (i.e., what proportion of vehicles on the road are CASE vehicles), the geography of a city (e.g., radial vs. ring roads), and the application of different policies and regulations (e.g., dedicated CASE vehicle lanes). Gains in road capacity (i.e., being able to have more vehicles on the road at the same time) depend on the level of diffusion, as platooning and reductions in the distances between vehicles are only possible under some scenarios (e.g., Mena-Oreja *et al.*, 2018; Schmitz & von Trotha, 2018). For example, in their simulations, Schmitz and von Trotha (2018) found a 16% decrease in road capacity with 50% penetration of autonomous vehicles, but an increase in road capacity of over tenfold with 100% CASE vehicles. As well, regulatory decisions about the allowable safety gap between vehicles will influence the magnitude of the improvement to road capacity with ADAS (e.g., Ntousakis *et al.*, 2015). Predictions are complicated by interactive effects as, for example, the benefits of designating a CASE vehicle-only lane are only realized after a threshold diffusion level is met; before that, a CASE vehicle-only lane appears to cause a reduction in road capacity and worse traffic problems (e.g., Talebpour *et al.*, 2017; Ye & Yamamoto, 2018).

Modelling suggests that automated driving systems could decrease emissions by up to 14% through smoother accelerating and braking; however, these reductions could be offset by increased travel distances (Liu *et al.*, 2017). Some experimental evidence suggests that gains in air quality (through reduced emissions) may be achievable with relatively low diffusion rates (~5%) if autonomous vehicles are designed to influence the behaviour of surrounding vehicles by dampening traffic waves and reducing stop-and-go events (Stern *et al.*, 2019). However, while stop-and-go behaviour can decrease with a combination of CASE vehicles and dynamic routing in urban centres, it also allows for higher cruising speeds and acceleration that may increase NO_x emissions (Tu *et al.*, 2019). The influence of CASE vehicles on traffic flow, particularly with a mix of human drivers and CASE vehicles, is a function of their programmed behaviour; while more aggressive automated driving smooths traffic flow on highways, more cautious programming can deteriorate flow and lead to increased emissions (Stogios *et al.*, 2019).

Electrification will reduce GHG emissions

Though electrification will not address pollution from tire and brake wear, CASE vehicles are likely to reduce tailpipe emissions drastically. Greenblatt and Saxena (2015) estimated that a battery electric autonomous taxi could reduce GHG emissions by 87 to 94% per kilometre when compared to a vehicle with an internal combustion engine, ultimately reducing total GHG emissions despite a predicted increase in VKT. If the electricity used to power such vehicles is not generated from a clean source, overall emission reductions will not be as drastic, and there is likely to be little (if any) change in air quality and health outcomes (Glazener & Khreis, 2019). In Canada, 80% of electricity generation comes from low-emission sources, such as hydroelectric, nuclear, or renewable sources (PwC Canada, 2018). Notably, the lifecycle GHG emissions of EVs in Ontario are, on average, about 4% that of ICE vehicles because of the province's reliance on predominantly clean electricity (Maroufmashat & Fowler, 2018). Challenges must be overcome before EVs can fully replace ICE vehicles, including higher capital costs, limited driving range, lack of recharging infrastructure, and long recharging time (Andwari *et al.*, 2017; AAA, 2019). Nevertheless, all of these areas are constantly improving. The adoption of EVs is also likely to lag in rural and less developed areas, leading to geographic variation in the resulting reductions in GHG emissions (Glazener & Khreis, 2019). However, electricity is significantly less expensive (~50% less) than gasoline use in conventional vehicles (Rodier, 2018), even in areas with higher electricity costs, such as rural Ontario (Williams, 2017).

7.1.2 Impacts on Emissions in the Canadian Context

As is evidenced in literature reviews of vehicle emissions models (e.g., Narayanan *et al.*, 2020), the predicted impacts of CASE vehicles on emissions is context dependent. However, few, if any, studies have examined the emissions implications of CASE vehicles in Canadian cities. Alam and Habib (2018) modelled the impacts of CASE vehicles on morning commute traffic in Halifax, Nova Scotia, though the study was focused on the transportation network effects and did not examine emissions impacts. Ticoll (2015) estimated the cost benefits of CASE vehicles to the city of Toronto to be $6 billion per year at a 90% adoption rate from reduced collisions, congestion, insurance, and parking fees and fines. While the potential benefits of CASE vehicles to the environment were noted in the report, they were not explicitly modelled for the city of Toronto (Ticoll, 2015). The Panel was therefore interested in examining how models of CASE vehicle impacts on emissions might apply in a Canadian city.

This model does not directly consider shared mobility due to the complexity of creating a shared mobility demand model, and variation in the impacts of different types of shared mobility (i.e., ride hailing, car sharing, ride pooling) on travel behaviour. However, CAVs in this model are assumed to be electric vehicles.

To that end, the Panel asked Z. Le Hong to model changes in emissions resulting from increasing levels of diffusion of electric CAVs between 2030 and 2040 in Metro Vancouver, British Columbia (Le Hong, 2020). For this study, CAVs are vehicles capable of travelling autonomously within the Metro Vancouver area. Emissions were estimated using the Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES), which estimates exhaust and evaporative emissions, as well as brake and tire wear emissions, from all on-road vehicles at multiple scales (USEPA, 2019). The model considered a range of CAV diffusion scenarios using baseline data from a 2015 study of Metro Vancouver emissions (Metro Vancouver, 2015). Data were then altered and scaled based on projections for weather (IES, 2019), population (City of Vancouver, 2012), VKT (based on population size and stated public transit goals), and fuel type usage (based on stated EV policy goals). These projections led to estimates for high and low CAV diffusion, transit use, and VKT scenarios for 2030 and 2040 (Table 7.1).

Table 7.1 MOVES Model Scenario Ranges

	Baseline (2020 values)	**2030** (estimated range)	**2040** (estimated range)
CAVs (% diffusion)	0%	1 to 10%	5 to 85%
Transit use (% trips)	17%	5 to 25%	5 to 33%
VKT (per capita)	Current	± 10	± 20

Source: Le Hong (2020)

Ranges for CAV diffusion, transit use, and vehicle kilometres travelled (VKT) for different future scenarios used in the MOVES model. In the baseline year of 2020, current values for VKT per capita were taken from MOVES model inputs from the 2015 Lower Fraser Valley Air Emissions Inventory and Forecast (Metro Vancouver, 2015).

CAVs will not reduce GHG emissions unless there is also a reduction in VKT

The vast majority of changes to GHG emissions are attributable to changes in VKT, with limited impacts from other variables in the MOVES model (Figure 7.2). Other models have also noted the potential for substantial increases in energy consumption due to vehicle automation, driven in large part by reductions in travel costs leading to an increase in vehicles on the road (Wadud *et al.*, 2016). While the range of model outcomes are greatly expanded for 2040 projections, representing higher uncertainty, it is telling that the worse-case scenario shows GHG emissions exceeding the 2020 baseline values, even with projected increases in vehicle electrification (Figure 7.2).

Particulate matter air pollution goals are unlikely to be met with or without CAVs

Particulate matter air pollution (e.g., $PM_{2.5}$) causes both acute and chronic respiratory health impacts (Matz *et al.*, 2020), and even low levels of ambient $PM_{2.5}$ have been linked to an increased risk of mortality in Canada (Christidis *et al.*, 2019). While individual CAVs had lower particulate matter emissions, the overall increase in VKT resulted in no scenario reducing $PM_{2.5}$ below current 2020 levels in 2030 without combined reductions in VKT and increased public transit use, and only the most optimistic scenarios reducing this pollutant in 2040 (Figure 7.2).

Vehicle electrification and smoother travel by CAVs reduce tailpipe emissions

Vehicle electrification was associated with emissions scenarios that produce even greater reductions than targeted in 2030 and 2040 goals for carbon monoxide, nitrogen oxides, and benzene emissions. Smoother driving behaviour by CAVs (i.e., a reduction in traffic waves) was associated with lower volatile organic compound and methane emissions. Better air quality is achievable with higher diffusion of CAVs, but mobility solutions that lower VKT are key to achieving emissions goals. Land-use patterns (e.g., population density, mixed-use development) are consistent determinants of VKT per capita (Woldeamanuel & Kent, 2014); therefore, without significant changes in ride-pooling behaviour, CAVs are unlikely to lower VKT in the next 10 to 20 years. However, the model suggests a threshold diffusion of about 5% for which CAVs can have a significant impact on lowering emissions though traffic-smoothing effects. CAVs do hold the promise of environmental benefits in the transportation sector; however, they depend on the mobility choices of people in Canada, which, in turn, reflect policy and investment decisions by government and transit agencies that influence the character of the mobility system.

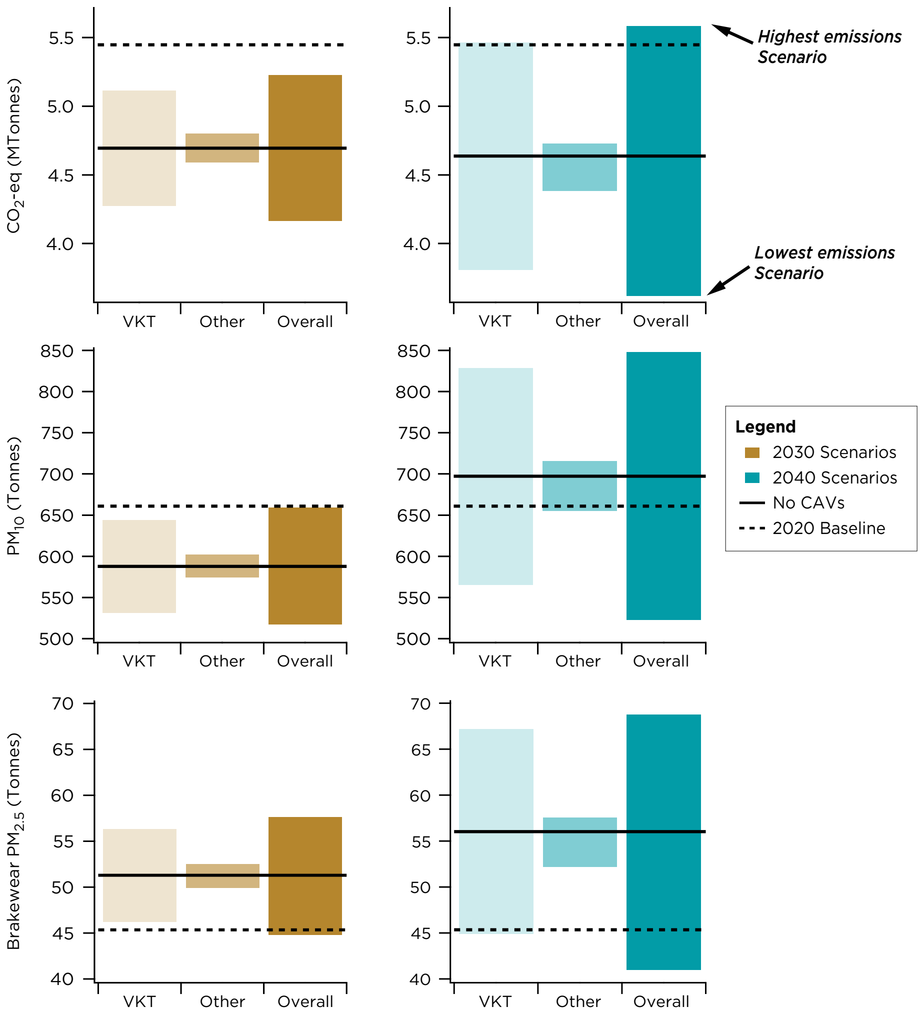


Figure 7.2 Emissions Scenarios for CAV Diffusion in Metro Vancouver in 2030 and 2040

MOVES model estimates for emissions of GHG (CO_2-equivalent; top), PM_{10} (middle), and $PM_{2.5}$ (i.e., brake wear; bottom) projected into 2030 and 2040. The dashed line indicates the baseline (2020) and the solid black line indicates projected emissions with no CAV diffusion in 2030 and 2040. Vehicle Kilometres Travelled (VKT) (left, lighter-coloured bars) had by far the greatest impact on overall emissions (right, darker-coloured bars). The "Other" category (middle, light-coloured bars) collectively includes the impacts of changes to fraction of trips on transit, average vehicle speed, number of vehicle starts, and drive cycle smoothing.

7.2 Road Safety

The number of collisions in Canada resulting in injuries and fatalities dropped by 27% and 34%, respectively, between 1999 and 2018 (TC, 2019d). However, motor vehicle collisions still caused 1,922 fatalities and 9,026 serious injuries in Canada in 2018 (TC, 2019d). About 30% of collisions causing injuries and 66% of fatal collisions occur on rural roads; these occur mainly on undivided roads and are often associated with high speeds, alcohol use, and non-use of seatbelts (TC, 2011). Although CASE vehicles could help to improve road safety in rural areas, it is unlikely that they will be widely available or useable within the next decade, particularly where automated driving features (e.g., lane keeping) are dependent on infrastructure features (e.g., road markings).

ADAS technologies are improving road safety today

Some autonomous emergency braking systems have reduced rates of rear-end collision by 41%, injuries from such collisions by 47%, and third-party injuries from such collisions by 48% (Cicchino, 2016). Cars equipped with electronic stability control (ESC) have shown a reduction of 41% in collisions where ESC would apply when compared with older models of the same make that were not equipped with ESC (Chouinard & Lécuyer, 2011). Moreover, the reduction in collision rates was 51% for all ESC-sensitive collisions in Canadian weather conditions (snow, ice, slush) (Chouinard & Lécuyer, 2011). Lane departure warnings (LDW) have reduced rates of single-vehicle, sideswipe, and head-on collisions by at least 11%, and the rate of such collisions causing injuries by at least 21% (Cicchino, 2018). This reduction in collisions could potentially be doubled if LDW systems remained on; previous research shows that drivers switch off LDW systems about 50% of the time (Cicchino, 2018). Ongoing development and refinement of ADAS, as well as driver training, are important for improving road safety with these systems. For example, lane-keeping assistance systems, which keep track of a vehicle's position between two lane markers and will automatically adjust the steering angle control to maintain its position within the lane, can feel unpleasant and intrusive for drivers, negatively impacting driver experience (Park *et al.*, 2018).

CASE vehicles will reduce human error in driving

Road safety is widely cited as one of the main benefits of CASE vehicles. Estimates in the literature range from 50 to 90% for safety improvements from automation, and increase with the share of such vehicles on the road (Ticoll, 2015). For example, Fagnant and Kocklman (2015) estimate 50% fewer collisions with a 10% market share of CASE vehicles on the road, and 90% fewer collisions when 90% of vehicles on the road are CASE vehicles. Other sources suggest that approaching 75% uptake of CASE vehicles on the road would nearly eliminate traffic fatalities and injuries (SSCTC, 2018). A widely cited statistic from the United States National Highway Traffic Safety Administration (2015) claims that human drivers are the *critical reason*[9] for approximately 94% of motor vehicle collisions, with vehicle failure accounting for 2% and environmental conditions such as roads and weather accounting for an additional 2%. Therefore, removing human factors from driving (such as speeding, inexperience, fatigue, inattention, distraction, performance errors, and intoxication) could arguably prevent up to 94% of collisions. However, some experts estimate CASE vehicles will prevent only 80% of collisions, as they also introduce the possibility of new types of technology-related errors (Godsmark *et al.*, 2015).

7.2.1 Safety Standards and Reporting

Establishing safety standards for CASE vehicles is a challenge for multiple levels of government

As levels of driving automation increase and vehicle users rely more on automated systems to perform the driving task, it will become increasingly important to establish whether automated driving systems are sufficiently reliable and robust for safe deployment. The acceptable level of safety for CASE vehicles is not yet established. The federal *Motor Vehicle Safety Act* (MVSA) sets safety regulations and standards for the importation of motor vehicles into Canada, and provincial and territorial legislation governs the safe operation of vehicles on public roads (TC, 2019f). The MVSA includes the *Canadian Motor Vehicle Safety Standards* (CMVSS), which establish minimum performance levels for vehicles and related equipment. At this time, no provisions within the MVSA, and no standards within the CMVSS, directly address CASE vehicle technologies (TC, 2019f). Exemptions in the MVSA allow the importation of CASE vehicles that do not comply with the CMVSS for exhibition, demonstration, evaluation, or testing (TC, 2019f). Guidelines for safety testing of highly autonomous vehicles (SAE Levels 3 to 5) are available, but are not legally binding (TC, 2018a). Given the early stages of CASE vehicle technology, further data collection and analyses are needed before establishing safety standards for deployment. Amendments to provincial, territorial, and municipal regulations will also be required to address the safe operation of CASE vehicles.

Statistical approaches to evaluating CASE vehicles against human drivers that rely on comparing the number of collisions per VKT will not be feasible (Gingras, 2019).

9 The NHTSA describes a *critical reason* as "the immediate reason for the critical pre-crash event and is often the last failure in the causal chain of events leading up to the crash. Although the critical reason is an important part of the description of events leading up to the crash, **it is not intended to be interpreted as the cause of the crash nor as the assignment of fault** to the driver, vehicle, or environment" (NHTSA, 2015 emphasis added).

Severe or fatal collisions are a statistically rare event considering the millions of kilometres vehicles travel each day. In 2018, there were 4.9 fatalities per billion VKT in Canada (TC, 2019d). Thus, the minimum distance that CASE vehicles would have to travel to establish their safety relative to human drivers to a statistically significant level — that is, to establish a lower rate of fatal collisions with enough data to ensure that observed differences are not by chance — would be billions or even hundreds of billions of kilometres (Kalra & Paddock, 2016; Gingras, 2019). The wide heterogeneity in hardware and software systems in CASE vehicles produced by different manufacturers also poses challenges in developing standardized approaches to safety data analysis, and the continuing evolution and development of CASE vehicles over both the short term and the long term adds further complexity (Gingras, 2019). Therefore, safety testing data from CASE vehicles will need to be evaluated using methodologies other than direct comparisons, such as using virtualization and computing tools to identify and examine only the most risky scenarios, using simulations to accrue data on CASE vehicle driving behaviour, and testing under limited scopes of operation (Gingras, 2019). Ultimately, regulators and stakeholders, including the public, will need to make decisions about acceptable and tolerable levels of risk in the deployment of CASE vehicles.

Data collection and reporting frameworks may need to be updated for CASE vehicles

Greater sharing of data could partially address the challenges around safety evaluation for CASE vehicles. CASE vehicles have the unique ability to "learn" from one another, insofar as data collected from a safety failure in one CASE vehicle can be analyzed and shared with the rest of the fleet to avoid similar failures in other vehicles (Ehsani *et al.*, 2020). Moreover, the entire CASE vehicle mobility system becomes safer with systematic data collection and pooling. For example, the aeronautics industry uses such data-sharing practices to improve safety and reliability (Ehsani *et al.*, 2020). However, while data pooling can be effective, program design needs to incorporate incentives for participation. Many companies may be reluctant to share potentially valuable intellectual property such as proprietary safety testing data. These issues need to be addressed before implementing a data-pooling system across the CASE vehicle industry (Ehsani *et al.*, 2020). Indeed, some have argued that federally legislated, mandatory data-sharing frameworks should be part of the safety standards for autonomous vehicles in the United States (Krompier, 2017).

Even with a data-pooling system for CASE vehicles, there is also a need for better data collection and police reporting for all vehicle collisions, as well as for updating the structure of the relevant databases. Current frameworks for compiling collision data must be able to take into account CASE vehicle technology and their associated safety risks and possible failures (Ryerson *et al.*, 2019). The U.S. Department of Transportation has identified information on collision and near-miss events involving CASE vehicles as a data priority, along with the development of a standardized reporting framework (USDOT, 2018). Some stakeholders suggest a requirement that all new CASE vehicles have "black boxes" (i.e., event data recorders) to provide information for first responders and subsequent investigations (Hightower, 2018). The Panel notes such data may also be of value to government agencies (for safety monitoring and developing regulation), insurance companies (for assessing and processing claims), and municipal planners (for urban and infrastructure planning related to vehicle safety), among others. Proposed versions of the long-established vehicle safety paradigm, the Haddon Matrix, for CASE vehicles at SAE Level 3 (Ryerson *et al.*, 2018) and Levels 4 and 5 (Ryerson *et al.*, 2019) delineate the roles of and interactions between the driver, the vehicle, the physical environment, and the social environment in causing or preventing collisions.

7.2.2 Road Safety Challenges with CASE Vehicle Diffusion

Unique safety issues may arise during the transition period to CASE vehicles

The transition period to a majority of CASE vehicles on the road will see a combination of CASE vehicles and conventional vehicles, along with the ongoing presence of pedestrians, cyclists, and motorcyclists. The impacts on safety during this transition period are uncertain: safety may not increase markedly and may even decrease until there are high percentages of CASE vehicles on the road (Milakis *et al.*, 2017). Drivers of conventional cars, as well as pedestrians and cyclists, may take additional risks when they encounter an autonomous vehicle, resulting in new types of accidents (Litman, 2019). For example, human drivers might mimic CASE vehicle platooning and follow too closely, or over-confident pedestrians may walk in front of a CASE vehicle (or a conventional vehicle they assume is a CASE vehicle) assuming it will stop for them (Cavoli *et al.*, 2017). Concern over this transition period has some public health advocates promoting the rapid uptake of CASE vehicles to maximize the safety benefits (Pettigrew *et al.*, 2018).

Concerns about the safety of SAE Level 3 vehicles during the progression to full automation also exist (Cavoli *et al.*, 2017; Chan, 2017). Level 3 vehicles do not require drivers to pay attention to the road or monitor the performance of the ADS, but they do require them to be able to take over "in a timely manner" when provided with a request to intervene (SAE, 2016). According to critics, this makes them uniquely dangerous. Research in cognitive science suggests that sustained attention and quick reengagement is very difficult for human drivers, especially if they are distracted by other tasks (Anderson *et al.*, 2016). Because of the problems with human attention and reengagement, some stakeholders believe that Level 3 is not the ideal path for deployment; instead, they advocate for transitioning directly to Level 4 vehicles (Anderson *et al.*, 2016; Chan, 2017; SSCTC, 2018). However, safety concerns around automated driving are not limited to vehicles at Level 3 automation or below. Although significantly fewer interactions occur between human drivers and the vehicle at Level 4, they still do occur. The unpredictability of such interactions can negatively affect the safe operation of autonomous vehicles (Ryerson *et al.*, 2019).

Better ADAS could lead to an over-reliance on automation

Automation bias is "the errors drivers tend to make in automated decision-making contexts that can cause them to 'over-trust' a vehicle's ability to carry out the driving function on its own" (Kerr & Millar, n.d.). Most recent collisions involving ADAS have been due in part to human drivers apparently over-relying on the self-driving abilities of the vehicle. A contributing factor to this trend may be the marketing campaigns of manufacturers over-emphasizing the automated driving capabilities of their vehicles (Kerr & Millar, n.d.). Reducing the risks associated with automation bias requires policymakers, manufacturers, and users to accurately and clearly define and understand the reliability, capability, and limits of the operational design domain for CASE vehicle technology. They must also understand how these capabilities and limitations may lead to collisions in situations where human drivers act in unanticipated ways or when CASE vehicle technology functions (or malfunctions) in unexpected ways (Ryerson *et al.*, 2018; Ryerson *et al.*, 2019). For example, the introduction of anti-lock brakes (ABS) increased the rate of certain types of collisions in the short term; vehicles with ABS were 24% more likely to be involved in fatal collisions than non-ABS versions of the same vehicle model (Ryerson *et al.*, 2019). Two primary reasons for this decrease in vehicle safety were: (i) drivers were unaccustomed to ABS and not trained in their proper use, or (ii) drivers familiar with ABS chose to drive their vehicles under more dangerous conditions, relying on ABS to provide safety benefits that they were not designed to provide (Ryerson *et al.*, 2019). As more vehicles with higher levels of automation become common in Canada, provincial and territorial governments will need to consider changing approaches to driver education and training, as well as licensing requirements, to ensure that drivers understand how to safely operate vehicles at different levels of automation (PPSC, 2018).

CASE vehicles could be both too noisy and too quiet in certain circumstances

CASE vehicles may reduce urban noise pollution, a problem for residents of large cities where road traffic noise levels range from 65 to 83 decibels (dB) in areas with moderate traffic volumes (Maffei & Masullo, 2014). Road traffic noise higher than 53 dB during the day and 45 dB at night has been associated with adverse health effects (WHO, 2018). At higher speeds, tire road noise (rather than propulsion noise), which is present in both types of vehicles, dominates. Vehicles with lower weights and with low-sound tires are necessary to further reduce noise levels (Maffei & Masullo, 2014). Thus, reduced noise pollution from CASE vehicles will be most evident in slower traffic areas, such as the urban core, not only from electrification but also as the result of smoother traffic flows created by autonomous vehicles (Patella *et al.*, 2019). Noise pollution on highways may worsen if CASE vehicles lead to higher traffic volume moving at faster speeds in areas where tire road noise dominates (Patella *et al.*, 2019). Vehicle noise is also an important auditory cue for pedestrians and cyclists in both detecting vehicles and perceiving the speed and direction of a vehicle's approach, particularly for people with visual impairment (Stelling-Kończak *et al.*, 2016). Thus, manufacturers actually design additive vehicle noise for EVs travelling otherwise too quietly at low speeds (Roan *et al.*, 2017). The Panel notes that additive vehicle noise will also be relevant to CASE vehicle safety in urban areas.

7.3 Physical Activity

CASE vehicles may increase mobility, but decrease activity levels

Vehicle ownership and VKT have increased, and walking as a form of transportation has decreased, in the past 50 years (Brownson *et al.*, 2005). Lower physical activity levels during transportation in combination with less physical activity at work and home, and stable or increasing leisure time, has led to an overall decrease in physical activity (Brownson *et al.*, 2005). Longer driving times are associated with poor health-related behaviours (e.g., less physical activity) and poor physical and mental health outcomes (Ding *et al.*, 2014). Lack of physical activity is a major concern for the health of Canadians. In 2017, only 40% of children aged 5 to 17 and 16% of adults aged 18 to 79 met physical activity targets (StatCan, 2017b). Lower levels of physical activity are a contributing factor in higher rates of chronic disease (Stevenson *et al.*, 2016). Independent of physical activity, sedentary behaviour — an important risk factor for weight gain and for premature mortality — increased by 1.3% per year in the United States between 1965 and 2009, and is predicted to continue to increase to almost 42 hours per week on average by 2030 in the United States (Ng & Popkin, 2012).

CASE vehicles will increase people's willingness to be on the road more often and for longer periods, as time normally spent driving will be available for work or leisure. If trips that were previously completed by walking or cycling are substituted for a trip in a CASE vehicle, physical activity levels will decrease and sedentary behaviour will increase (Spence *et al.*, 2020). However, the impact on daily commutes may be minimal given that only 7% of Canadian commuters walked or cycled to work in 2016; most people in Canada already rely on personal vehicles for their day-to-day mobility (StatCan, 2017a). Commuting behaviour also varies geographically, with walking or cycling more common in some urban areas. For example, nearly 17% of commuters used active transportation to get to work in Victoria, British Columbia, in 2016, the highest proportion in Canada (StatCan, 2017a). Smaller cities such as Kingston and Peterborough, Ontario, also had a higher proportion of commuters using active transportation compared to the national average (StatCan, 2017a). If CASE vehicles are more likely to be first used in dense urban cores, as the Panel has previously discussed, then the impacts on active transportation will also be limited to those areas, which may or may not accurately reflect how smaller cities will respond.

CASE vehicles could also allow cities to become more bike- and pedestrian-friendly, encouraging active transportation. For example, CASE vehicles could make active transportation safer for cyclists and pedestrians if automation and connectivity reduce collisions and make the behaviour of vehicles safer and more predictable (Botello *et al.*, 2018). Researchers are exploring different forms of visual, universal cues (such as symbols and text in different positions on the vehicle and street surface) that can facilitate unambiguous signaling to pedestrians and cyclists (Ackermann *et al.*, 2019). Although active transportation can increase exposure to fine particulate matter through increased time outdoors, in all but the most polluted cities worldwide (none of which are in Canada) the benefits of physical activity generally outweigh the harm of exposure to air pollution (Glazener & Khreis, 2019). Still, as there is no safe level of exposure to air pollution, policies that encourage active transportation can have additive positive impacts on the environment and human health by reducing VKT (and therefore air pollution) among both conventional and CASE vehicles.

7.4 Summary

CASE vehicles have the potential to improve the environment, and the health and well-being of people in Canada, but this potential will not be met through technology alone. Environmental benefits largely depend on reducing VKT, through, for example, encouraging public transit, active transportation, and ride pooling, and discouraging single-occupancy vehicle trips. While CASE vehicles promise to improve road safety by removing human error from driving, such promises will need to be tested against robust data on both CASE vehicle and human driving performances. Mobility choices for Canadians, particularly in urban areas, will change with the appearance of CASE vehicles. While CASE vehicles might create more pedestrian- and cycling-friendly roads by reducing the likelihood of collisions, they might also replace active transportation as a convenient and cost-effective means of making short trips, thus reducing physical activity levels. The environmental and health impacts of CASE vehicles are intertwined; the benefits depend on lowering VKT more so than on the availability of new technology.

8

CASE Vehicles and Shared Mobility in Canada

Answering the Charge

The Panel's response to the charge assumes that the first commercial appearance of connected and autonomous vehicles for consumers will likely be through shared mobility. The Panel also assumes that the trend towards electrification of all vehicles will continue at pace; thus, its analysis has considered the four separate technological trends (connected, autonomous, shared, and electric) as one. CASE vehicles hold the promise of a transportation revolution, with the benefits of more environmentally friendly, safe, and accessible transportation for people and goods in Canada. However, there is substantial uncertainty regarding when, how, and even if such benefits will be realized. Predicting the impacts of CASE vehicles on people in Canada is complicated because they will reflect decisions made by a multitude of stakeholders, often uncoordinated in their decision-making, and which include three levels of government, as well as industry and consumers.

Recall that in this report, *autonomous* is used to describe an object (e.g., autonomous vehicles) and *automated* is used to describe a process or action (e.g., automated driving).

Many decision points unconnected to the technology itself will shape the deployment of CASE vehicles in Canada. For example, decisions to support and encourage public transit, ride sharing, and active transportation can help ensure that CASE vehicles complement diverse transportation options. Alternatively, decisions that prioritize and encourage personal vehicles as the dominant mode of transportation could result in CASE vehicles exacerbating issues of traffic and curbside access in dense urban areas. Therefore, despite their many potential benefits, CASE vehicles could just as likely contribute to increased transportation inequities, congestion, and pollution if specific policy measures are not introduced to prevent these outcomes.

THE CHARGE

In light of the current trends affecting the evolution of connected and automated vehicle technologies and shared mobility, what impacts, opportunities and challenges do these present for Canadian industry, governments, and Canadians more broadly?

Table 8.1 summarizes the main issues identified by the Panel related to the development and diffusion of CASE vehicles over the next 10 years. These issues may be approached as either challenges or opportunities; the range and magnitude of the issues underscore the complexity of the changes required in order to address them.

Table 8.1 Areas of Opportunity and Challenge for the Development and Deployment of CASE Vehicles in Canada Over the Next 10 Years

Industry

Motor vehicle and parts manufacturing	ICT	Shared mobility
Transition to ICT R&D by manufacturers and parts suppliers	Incorporation of new companies and technologies into automotive supply networks	Growing markets and opportunities for expansion of services in urban areas
Production mandates for CASE vehicles and components essential for long-term relevance of Canadian manufacturers and suppliers	R&D and scale-up for new technologies (e.g., AI, operating systems, sensors)	New companies including automotive manufacturers entering the market
Education, training, and re-training of labour force to meet skills required for CASE vehicle production and servicing	New opportunity niches (e.g., infotainment, financial services)	Public-private partnerships (e.g., transit authorities, municipal governments, and private companies)
Transition to new opportunity niches (e.g., battery recycling, AI components) important for mitigating impacts related to the obsolescence of internal combustion engines and related parts manufacturers		

Government

Federal	Provincial and territorial	Municipal
Innovation policy and investment strategies to address Canada's role in the CASE vehicle economy	Innovation policy and investment strategies to address Canada's role in the CASE vehicle economy	Traffic, parking, and curbside access regulations to address the growing share of CASE vehicles
Trade agreements to clarify relationships for international companies and investors	Support and transition strategies for regional economies vulnerable to changes in the automotive sector	Infrastructure planning, upgrading, and maintenance to support the safe operation of CASE vehicles
Vehicle safety guidelines and standards for new technologies	Insurance regulations, traffic laws, and driver training and licensing changes to address increasing levels of automation	Transportation and mobility planning and regulation (i.e., integration of multiple services)
Harmonization of Canadian automotive and ICT regulations with the United States	Infrastructure planning, upgrading, and maintenance to support the safe operation of CASE vehicles	Urban planning and zoning decisions (e.g., urban density, access to public transit)
Communications infrastructure investments, standards, and regulation (including data privacy)	Education and training to ensure a skilled workforce in the CASE vehicle sector as well as in new opportunity niches	Public-private partnerships and new revenue streams (e.g., congestion pricing)
Environmental pollution and air quality standards in light of new technologies	Environmental pollution and air quality standards in light of new technologies	Mobility-as-a-Service (MaaS) opportunities (i.e., the integration of multiple offerings)
Infrastructure investment to support equitable access across communities (e.g., rural connectivity)		

8.1 Industry

What economic, social and environmental implications will these technological trends have on Canadian industry, including automotive as well as other industries that could be affected by technology trends and changing business models? Include opportunities for the Canadian industry.

The demand for vehicles in Canada will not change dramatically in the next 10 years

While the trend towards increased shared mobility services is likely to eventually result in fewer personal vehicle purchases, such trends will be limited to geographic areas with a high enough population density to support convenient and affordable on-demand services. People in Canada living outside of urban centres will still have to rely on personal vehicles for the majority of their mobility needs. Since the average age of a personal vehicle in Canada is nearly 10 years, it will likely take decades for CASE vehicles to make up a substantive proportion of the overall Canadian fleet. Consumer demand for EVs in Canada has been low, and the increasing uptake of EVs in Canada and elsewhere is more a function of policy incentives than consumer preference. Policy incentives may therefore play a significant role in the speed and breadth of CASE vehicle adoption in Canada, as well as in the prioritization of CASE vehicle technology development and commercialization for industry.

The automotive industry is betting on an EV future

With the cost of batteries plummeting and the public demand to address climate change increasing, automotive manufacturers are investing in EV development. Canadian companies and facilities will look to secure new production mandates at existing facilities, particularly for EV parts and assembly. Companies that produce parts and provide services for internal combustion engines will eventually face either transformation or obsolescence. The transition to electrification will also be influenced by vehicle turnover rates, the availability of charging stations, consumer acceptance and demand for different powertrains (high-efficiency ICE, hybrids, fully electric), and policy incentives. These factors could lead to a relatively slow uptake of fully electric vehicles in Canada, particularly outside of urban cores. The trend towards electrification, however, will increase demand for mineral extraction, battery production, battery recycling, and clean energy — areas in which Canada is well positioned to expand.

The role of Canadian companies in the CASE vehicle industry is uncertain

The integration of manufacturing with the network economy is disruptive for OEMs and parts suppliers, which must compete in expensive R&D or face obsolescence in the new marketplace. While growth in the ICT sector is ongoing and many companies in Canada actively operate in this space, the motor vehicle and parts manufacturing sector is struggling to remain competitive with current operating costs, regulations, trade uncertainties, and increasing competition from low-wage areas. Government incentives largely support the maintenance and upgrading of existing facilities, but have not generally attracted new builds or growth in light vehicle production. Over the next 10 years, transit vehicles and the electrification of commercial vehicle fleets present opportunities for expansion in Canadian manufacturing and markets.

Canadian ICT companies are also developing and producing technologies for CASE vehicles. Despite Canada's academic and industrial research strength in ICT, a lack of domestic OEMs has contributed to lower automotive R&D investment. As the automotive industry merges with the ICT industry, the number of companies may first proliferate, but then contract and restructure through mergers, acquisitions, and bankruptcies, ultimately reducing the number of global players to one or two dominant companies and their networks of subsidiaries including parts suppliers, software developers, insurance providers, aftermarket parts and repairs dealers, and infotainment providers. The considerable uncertainty and intense competition in the CASE vehicle industry globally makes it difficult to predict the implications for Canadian industry with any specificity, though integration of Canadian ICT firms into OEM supply chains will likely be one of the more significant challenges for this sector.

CASE vehicles will create opportunity niches in ICT, mobility services, and insurance

CASE vehicles will create new opportunity niches and likely lead to job gains in the ICT sector and shared mobility services industry as well as in data management and analytics. Although Canada's mobility system is characterized primarily by personal vehicle ownership, the use of shared mobility services is expected to grow as convenience and affordability improves, albeit more slowly outside of the densest population centres. Some OEMs are openly discussing diversifying from automotive manufacturing to mobility services.

The data from connected vehicles present an opportunity for the aftermarket services industry to improve diagnostics and parts supply. Many companies that make telematics systems or use AI for predictive diagnostics from vehicle data, however, are focusing on selling their product to OEMs rather than to the aftermarket industry directly. For the aftermarket industry, access to these data present growth opportunities for better repair and maintenance services. Access to CASE vehicle data could also help grow insurance products, transportation management services, mobility services, and other sectors. The infrastructure demands of CASE vehicles, including charging stations, battery recycling, and telecommunications devices present new opportunities for manufacturing and R&D, as do the vehicles themselves. CASE vehicles may also cause the consolidation of insurance companies across the industry, and new, non-traditional competitors may enter and disrupt the industry.

8.2 Governments

What economic, social and environmental implications will these technological trends have on government policy and regulations in Canada?

Regulatory decisions at all levels of government will shape CASE vehicle deployment

In Canada, federal, provincial and territorial, and municipal governments have different roles and jurisdictional authority in the regulation of transportation. The implications of CASE vehicles for government policy and regulation therefore vary depending on the level of government. To realize the potential benefits of CASE vehicles, governments will need to review insurance regulations and legislation; vehicle safety standards; road and traffic safety standards; data ownership, privacy, and cybersecurity legislation; and driver training and licensing requirements. Harmonization of standards and regulation with other countries, particularly the United States, will be essential for the seamless operation of CASE vehicles across borders. As municipal and provincial planning can extend 20 to 30 years into the future, CASE vehicles will need to be considered in relation to municipal zoning laws, transportation planning, and the maintenance and upgrading of infrastructure. Government decisions made today about infrastructure and funding related to active transportation, public transit, and congestion and parking, for example, will direct the use of CASE vehicles in the future.

Innovation in the CASE vehicle industry in Canada will benefit from government support

The mass production and manufacturing of CASE vehicles is likely to fundamentally change the industrial structure of Canada's automotive sector, as the vertically integrated motor vehicle and parts manufacturing industry merges with the networked and more horizontal structure of the ICT sector. CASE vehicles create opportunities for R&D expansion in the automotive industry, though is it unclear whether Canada will be able to attract and maintain R&D commitments from both international and domestic firms without a sustained, coordinated, and large-scale public policy regime to support such activities. For Canada, the impact of the shift to CASE vehicles will be influenced by how well automotive companies adapt to evolving production networks, and whether production mandates are secured for new technology vehicle assembly in Canada, which historically has required government support. Nurturing a competitive and innovative automotive ecosystem in Canada will require ongoing support for R&D and collaboration across governments, academia, and industry.

CASE vehicles will likely require substantial infrastructure investments

The safe operation of CASE vehicles may require a substantial overhaul of existing transportation and communications infrastructure, as well as some standardization of road markings and signage across provincial and territorial boundaries. Alternatively, CASE vehicles may be developed to use existing infrastructure (i.e., not rely on V2I to operate safely), though the quality and maintenance of existing infrastructure (e.g., visible lane markers) may still limit where such vehicles are used. The cost of upgrades, as well as maintenance demands, may be greater than many, if not most, municipalities will be able to afford. Planning for infrastructure upgrades will need to take into account the demand that CASE vehicles will shortly place on elements such as connectivity, the electricity grid, and road maintenance. However, achieving such improvements will require coordination and cooperation across all levels of government as well as substantial financial investments in infrastructure upgrades, management, and maintenance. Currently, the testing of CASE vehicles largely occurs in urban settings; rural areas may lack the infrastructure needed for their safe operation for some time. Lack of connectivity is already an issue in rural areas and could further limit CASE vehicle operation.

CASE vehicles could decrease parking fees and parking ticket revenues for municipalities, but new revenue streams, such as congestion pricing and zero- or low-occupancy tolls, could help pay for infrastructure and encourage behaviours that reduce traffic congestion. It is unlikely, however, that new revenue streams will be sufficient to cover infrastructure costs. Public-private partnerships are one option being explored today, though they are not without trade-offs. Moreover, it is unclear the extent to which infrastructure investments will be necessary to ensure the safe operation of autonomous vehicles; such investment needs could further limit the availability of CASE vehicles to specific neighbourhoods within large cities.

CASE vehicles on their own will not reduce traffic congestion

The solution to traffic congestion is available today: reduce the number of vehicles on the road. Policies that encourage car or ride pooling, public transit use, and active transportation, and that discourage single-occupancy rides in personal vehicles, can reduce congestion without the need for greater automation in driving. Opportunities to improve traffic management are increasing given the growing share of connected vehicles travelling on roads in Canada. With increasing levels of automation, CASE vehicles may allow transportation engineers to alter lane widths, speed limits, parking, curbside access, and other design factors to promote active transportation (cycling, walking) and public spaces (parks, walkways) and improve the desirability of living in certain neighbourhoods.

Liability and fault in collisions involving CASE vehicles need to be resolved if automated driving is to become more widespread

Current laws and regulations on liability and fault determination in motor vehicle collisions will need to be revised and updated with the increased prevalence of automated driving technology. While the improved safety of CASE vehicles is expected to cause auto insurance premiums to decrease over the long term, premiums may actually increase over the next 10 years due to increases in the cost of repairs, initial technology glitches, and the combination of human and automated driving, particularly with SAE Level 3 automation. The shift in liability from human drivers to automated technology could require individuals injured in collisions involving CASE vehicles to seek compensation through product liability litigation, which is typically several years longer and more complex to resolve than traditional auto liability litigation.

New vehicle technologies will necessitate new safety standards

The promise of autonomous vehicles substantially reducing collisions causing injuries and fatalities depends on automated driving systems that perform better than human drivers and the mass adoption of CASE vehicles on roads in both urban and rural areas. The potential for a mix of autonomous and human-operated vehicles on roadways, and especially the combination of automated driving systems and human drivers in the same vehicle (SAE Level 3), could lead to worse road safety outcomes in the next several decades. Areas of particular consideration for regulatory agencies include:

- **Vehicle safety standards:** Regulation will need to be flexible and dynamic to reflect changing technologies. The federal government has developed guidance documents for the safe testing of CASE vehicles without stipulating specific regulatory requirements; however, Canada will likely follow the United States, Europe, and Asia when developing regulations, due to the need for cross-border harmonization of vehicle design and safety.
- **Road safety and traffic regulation:** In the next 10 years, these regulations could be updated to reflect the availability of advanced driver assistance features in all new vehicles, or mandate the use of existing technological solutions to aid in enforcement (such as speed limiters and breathalyzer ignition locks).
- **Driver training and education:** As CASE vehicles become more common and have higher levels of automation, revised approaches to driver education and training will be needed, as well as revised licensing requirements, in order to ensure that drivers follow proper driving behaviour for different levels of automation.

Safety gains through technological advancements are possible today with ADAS. Initiatives to encourage ADAS adoption and use, such as tax incentives, education programs, and updates to driver licensing, could reduce the number of collisions. Moreover, mandating the inclusion of ADAS technologies on all new vehicles could contribute to safer roads in the coming decades. Such improvements to road safety would not require waiting for fully autonomous vehicles to become widely available, and would provide benefits for vehicles routinely travelling outside of urban cores.

CASE vehicles exacerbate privacy and cybersecurity concerns

Technologies that collect and analyze personal information are currently outpacing the development of privacy and cybersecurity standards and regulations related to informed consent and data collection for CASE vehicles. Data ownership, access, and control issues need to be clearly defined, via either voluntarily adopted industry standards or government-imposed legislation or regulations. Moreover, CASE vehicle manufacturers and developers will need to develop data collection and management practices that are sensitive to different privacy laws in different jurisdictions. Competing claims of data ownership, as well as unprecedented volumes and new types of data, exacerbate privacy risks without clear directions for resolving disputes. Connectivity among CASE vehicles and across the Internet of Things increases the urgency of addressing issues of privacy and human rights in the digital space. The gradual accumulation of seemingly insignificant practices for data collection and use by a variety of different actors, though potentially legal, may collectively present a serious threat to personal privacy. Privacy by Design may become an important framework for proactively protecting personal information.

Insufficient cybersecurity measures can cause unique safety risks with CASE vehicles. There is the potential for malicious actors to gain control of a CASE vehicle to cause harm. Moreover, V2V communications could allow for the control of multiple vehicles simultaneously. Such attacks could be blatant (e.g., causing collisions) or insidious (e.g., re-routing vehicles, disrupting traffic flow, disabling sensors). Data generated by CASE vehicles could be used for identity theft, surveillance, blackmail, and other types of harm to passengers. Because the technology is both complex and still in development, it is difficult to predict vulnerabilities and establish security standards and protocols. Additional challenges also arise when it comes to designing security protocols that are compatible across different vehicles and platforms, as well as scalable across potentially millions of vehicles.

Success in the CASE vehicle market will require new skills and education

Automation and AI will necessitate skills training and education for a large portion of the Canadian workforce. Many manufacturing jobs will be affected by automation, necessitating an upskilling of workers for jobs in software development and transportation engineering and planning, as well as support for those for whom upskilling is not a reasonable option. As shared mobility services replace personal vehicles as the dominant mode of transportation, the transportation workforce itself will shift from drivers to safety operators and customer service agents. Tradespeople, such as mechanics, will require training in skillsets necessary to service CASE vehicles. Investment in education and skills training, and, importantly, continuous learning programs relevant to CASE vehicles (e.g., computer science, electrical engineering, ICT), will help ensure that Canada's workforce remains an asset to companies worldwide, while also helping transition the existing workforce to new opportunities as they arise. As CASE shuttles, taxis, and buses begin to displace human-operated vehicles, job losses for drivers can be expected in the transportation services industry. However, job losses in commercial trucking may be limited given the current driver supply shortage in Canada. Regardless, education, re-education, and continuous learning programs to ensure workers have and maintain the necessary technological skillset to contribute to the CASE vehicle economy will be an asset across diverse sectors, including ICT, automotive and parts manufacturing, aftermarket parts and repair services, infotainment, transportation engineering, and insurance and financing.

8.3 People in Canada

What economic, social and environmental implications will these technological trends have on Canadians?

CASE vehicles could improve accessibility for urban Canadians

Canadians overwhelmingly rely on personal vehicles as their main mode of transportation. A lack of access to a personal vehicle, whether due to age, ability, or finances, severely limits access to employment, health appointments, grocery stores, social events, education, and participation in civil society. A substantial potential benefit of CASE vehicles is in reducing the need to buy and maintain a vehicle to access on-demand mobility. However, the availability of these vehicles alone will not necessarily improve mobility; without support for public transit and active transportation, CASE vehicles will likely increase the number of vehicles on the road and lead to worse mobility services as compared to now.

In the next 10 years, residents of cities such as Toronto, Montréal, Edmonton, and Vancouver can expect to ride in a low-speed driverless shuttle or, possibly, hail a ride in a robo-taxi. These vehicles are likely to be limited to pre-determined routes in fair weather conditions. Most people living outside census metropolitan areas are unlikely to be substantially affected by CASE vehicles in the next decade.

Equity in mobility will depend on the access costs, design, and availability of CASE vehicles

By removing the need for human drivers, the diffusion of CASE shuttles and taxis will likely improve accessibility for older adults, people with disabilities, and children and youth. However, people who cannot access CASE vehicles for economic and geographical reasons may perceive their mobility as increasingly limited if mobility options in rural areas become relatively more expensive (i.e., as personal vehicle costs rise), especially when compared to those available in urban areas (e.g., active transportation, micromobility, public transit, ride hailing). On-demand mobility without the constraint of a driver could lead to a greater decentralization and specialization of neighbourhoods; alternatively, CASE vehicles could be an opportunity for urban centres to become more attractive and cost-effective places to live, with better access to autonomous mobility services, active transportation infrastructure, and public transit. Ultimately, equitable access to mobility will depend on the cost of CASE vehicle use, the design of vehicles and shared mobility systems, and the extent to which CASE vehicles are accessible in all neighbourhoods and rural areas.

CASE vehicles can increase vulnerability to privacy breaches and cybersecurity risks

Connected vehicles are already relatively common in Canada today and will become ubiquitous over the next decade. CASE vehicles are a part of a growing Internet of Things already generating and collecting vast amounts of data — including personal information — often without the explicit consent or awareness of users. The unprecedented volumes and new types of data collected by CASE vehicles represent a serious threat to the privacy and cybersecurity of vehicle drivers, owners, and passengers. Data collected or generated by vehicles in Canada may be transmitted and stored outside of Canada, and accessed or used by foreign companies and governments to identify individuals in Canada and predict their behaviour. Cybersecurity platform compatibility and shared design suggest significant vulnerabilities in the future. Moreover, because CASE vehicles are still vehicles, insufficient cybersecurity measures can cause unique public and private safety risks.

Environmental benefits from CASE vehicles depend on changing mobility behaviours

Mobility behaviours that lower the total VKT (e.g., ride pooling, active transportation, public transit) are essential to improving air quality, congestion, and public health in Canada. While electrification promises significant reductions in greenhouse gas and other tailpipe emissions, non-tailpipe emissions may increase if CASE vehicles lead to higher travel demand. Automated driving systems will likely drive more efficiently than people do, reducing emissions from stop-and-go traffic, though the mix of both could result in people driving less efficiently to avoid being stuck behind more sedately moving CASE vehicles. Raw materials extraction and processing, battery production and recycling, and emissions from vehicle manufacturing will be ongoing sources of pollution requiring mitigation and creating demand for ecological restoration. Moreover, emissions created from electricity generation may offset emission reductions gained from electrification, depending on how the demand for electricity or fuel cells is met. Battery and fuel cell recycling is an area of uncertainty, with the potential for increased demand for such services outpacing capacity in this sector. Evidence from other countries suggests the electrification of personal vehicles will be slow without policy incentives to encourage consumer purchases or in the absence of electric vehicles being used for government and corporate fleets and public transit.

CASE vehicles could improve road safety by reducing human error

A majority of collisions involve human error, such as fatigue, speeding, inexperience, inattention, distraction, performance errors, and intoxication. Advanced driver assistance systems, such as lane departure warnings and emergency braking, have proven to be effective at reducing collision rates. Safety testing of CASE vehicles is ongoing, and significant challenges remain in demonstrating safety gains over human drivers and developing standardized approaches to safety data analysis. There is also a need for better data collection and reporting of collisions involving conventional vehicles, in order to provide adequate information for comparing autonomous vehicles and human drivers and to develop appropriate standards. The mixing of human drivers and autonomous vehicles creates uncertainty around estimates of road safety gains. Moreover, vehicles with Level 3 automation, where humans must be attentive and able to take over control of the vehicle when it is driving autonomously, are a particular safety challenge that many experts recommend avoiding altogether.

8.4 Final Reflections from the Panel

Fully realizing the potential of CASE vehicles to improve safety, reduce travel time, save the environment, and grow the economy depends on government readiness, as well as industry and public action, in meeting potential challenges and taking advantage of opportunities. The issues facing CASE vehicle development and deployment are complex; resolving them will require coordinated interactions and decision-making among government authorities at all levels, as well as with relevant industry actors, associations, and international organizations. Technological developments that advance CASE vehicles will likely outpace social responses to the challenges they bring — including challenges in privacy, job losses, and equity — necessitating effective governance and frequent policy and regulatory updates.

Before autonomous vehicles become ubiquitous on Canadian roads, there will be transitional periods where human and automated drivers co-exist, sometimes in the same vehicle and potentially on the same roads. The rollout of CASE vehicles in Canada will be fragmented over time and over geographic location, with urban centres providing the earliest testing grounds for commercial deployment. The Panel views these transitional periods, especially in the next 10 years, as the most significant challenge to transportation safety. With the design of CASE vehicles occurring outside of Canada, the country's small market and regulatory environment will not be a significant consideration. This presents challenges for the regulation of vehicle safety and data protection, and, in the Panel's view, requires Canadian vehicle safety and design standards to align with U.S. Department of Transportation and NHTSA standards.

If Canada is to be prepared for the rollout of CASE vehicles, governments at all levels will need to consider future infrastructure needs for CASE vehicles in the design and development of current infrastructure projects. Any newly built infrastructure could quickly become obsolete if it is not built with CASE vehicles in mind. However, no one-size-fits-all approach exists, and specific policies will likely be required to target different types of transportation infrastructure needs in different areas (i.e., urban, suburban, rural, and remote). Planning choices about lane width, speed limits, parking, curbside access, and other design factors could promote active transportation (cycling, walking) and public spaces (parks, walkways). Vehicle occupancy taxes, congestion taxes, shared mobility subsidies, zoning for dense neighbourhoods, lowering the number of parking spaces, and investing in public transit may help promote shared mobility services over private vehicle ownership.

Finally, the promise of CASE vehicles — faster, safer, more environmentally friendly mobility for all — will not be met in Canada without government intervention and policies to encourage desired behaviours in both industry and individuals, nor without the public trust and acceptance of these new technologies. The economic, social, and environmental benefits of greater accessibility may be difficult to achieve without policy and regulation that support transportation equity and the integration of public transit and active transportation options with mobility services. The Panel hopes that the implications identified in this report can help direct efforts to prioritize policy and regulation in light of rapidly advancing CASE vehicle technologies in Canada.

Afterword: CASE Vehicles and COVID-19

Well into the Panel's year-long deliberations, the world experienced the widespread emergence of COVID-19, which raises critical questions about the potential impacts of the pandemic on the assumptions and findings in the report. The Panel recognized that the pandemic will undoubtedly have significant consequences for the CASE vehicle industry, for Canadians' mobility choices, and for government policy around CASE vehicles, not just in the short term but also within the 10-year horizon that is the main focus of the report. Though there is little reliable evidence yet available to justify its inclusion in the report, the Panel agreed that the topic warrants special consideration by way of this addendum. What follows is a review of the early discussions on the topic, most of which are from media reports, with the purpose of identifying the general contours of the potential implications of COVID-19 for CASE vehicles.

COVID-19 is likely to adversely impact the CASE vehicle industry, at least in the short term

Like many industries, the pandemic is likely to adversely impact the autonomous vehicle industry, at least in the short term (Abadi & VanderVeer, 2020; Tchir, 2020). Some autonomous vehicle companies are closing, some are being sold, and there have been layoffs of personnel (Metz & Griffith, 2020). Capital investment in autonomous vehicle companies could become more difficult to obtain (Metz & Griffith, 2020; Muller, 2020), and industry consolidation could be accelerated over the short term (Muller, 2020). Several companies have temporarily suspended or delayed on-road testing of autonomous vehicles (Metz & Griffith, 2020), and industry leaders generally agree that the pandemic has negatively impacted autonomous vehicle testing (Oliver, 2020). Ultimately, COVID-19 is likely to delay the deployment of autonomous vehicles (Hall, 2020).

The pandemic could slow the uptake of EVs, as fuel prices have decreased; EVs currently cost more up front than traditional vehicles, and automakers may be hesitant to invest in switching to EV production during an economic downturn (Ewing, 2020). Lockdowns during the pandemic have demonstrated the impact that vehicles with no tailpipe emissions could have on the environment: nitrogen oxide and ultrafine particles associated with vehicle emissions have sharply decreased — by roughly half — in areas of downtown Toronto (Xing, 2020). Similar reductions in nitrogen oxide emissions have been observed in other studies (Sarabia, 2020a). It has been suggested that infrastructure for EVs (e.g., charging stations) could be an effective government investment for post-COVID recovery (Sarabia, 2020b), as it would both support economic recovery and help to meet pre-existing policy goals.

Furthermore, there is more optimism in the auto industry about the future of EVs, given the relative maturity of the technology and the pro-EV incentives of the current regulatory environment (Hall, 2020).

COVID-19 has caused some shared mobility companies to pivot to delivery services

The pandemic has had a negative impact on the shared mobility industry. Use of car sharing, ride-hailing, and micromobility significantly decreased in the spring of 2020 due to lockdowns and concerns about social distancing and virus transmission (Ewing, 2020; movmi, 2020). Ford postponed the launch of its autonomous taxi service to 2022 because of the economic and behavioural challenges associated with the pandemic (Metz & Griffith, 2020; O'Kane, 2020), and GM permanently shut down operations of its car-sharing service (Hall, 2020). The pandemic has accelerated industry consolidation of shared mobility service providers (Audenhove *et al.*, 2020).

However, the pandemic has also spurred several shared mobility companies to pivot away from personal transportation and towards delivery services (Hall, 2020; movmi, 2020; SkedGo, 2020). Autonomous delivery vehicles have been used for food, medical supplies, and consumer products, as they offer a way to deliver essential goods while reducing the potential of person-to-person contact (Abadi & VanderVeer, 2020; Fitzgerald, 2020; Muller, 2020; Tchir, 2020). It is possible that over the long term, COVID-19 could spur both shared mobility and autonomous vehicle companies to focus more on delivery services than on personal transportation (Abadi & VanderVeer, 2020; Lienert & Lee, 2020).

COVID-19 has affected Canadians' mobility choices

COVID-19 has dramatically impacted mobility choices, and overall mobility has significantly decreased as people avoid travelling and limit time spent outside their homes (Audenhove *et al.*, 2020; Phillips & Rickmers, 2020). Health and safety have become the most significant decision factors in transportation during the pandemic (Phillips & Rickmers, 2020), as commuters look for mobility options that reduce their risk of viral infection (Audenhove *et al.*, 2020). Concerns around cleanliness and social distancing have become important factors in decisions about modes of transportation. Uber and Lyft have stopped offering pooled rides (ride sharing) due to virus transmission concerns (Ewing, 2020; movmi, 2020), and commuters' willingness to share pooled rides with strangers has been severely diminished, at least for the short term. The pandemic has also resulted in a shift towards individual transportation options such as personal vehicles and cycling, while public transit use has decreased sharply (Phillips & Rickmers, 2020); this trend is likely to continue in a post-COVID world (Audenhove *et al.*, 2020). There is some evidence, however, that the pandemic may have increased public interest in autonomous vehicles (Motional, 2020).

As shared mobility services have become less appealing during the pandemic, the viability of future CASE vehicle-based mobility such as robo-taxis and autonomous shuttles may be re-examined (Muller, 2020). Self-disinfecting will become an important task for such vehicles (Harper, 2020; movmi, 2020) and possible methods include spray disinfectants, UV lighting, and antimicrobial materials, as well as replacing touchscreens with voice commands (Muller, 2020). Similarly, concerns around health and safety have spurred changes to public transit, such as more cleaning and disinfecting, protective screens, improved air filters, and less dense seating (SkedGo, 2020).

COVID-19 may offer an opportunity for governments to "Build Back Better" with CASE Vehicles

Ultimately, the pandemic may help to highlight and clarify the most plausible use cases for CASE vehicles, and focus attention on the role and function of CASE vehicles in supporting essential transportation infrastructure (Abadi & VanderVeer, 2020). COVID-19 may spur governments to address regulatory hurdles to CASE vehicle deployment, as well as on infrastructure and urban planning for CASE vehicles (Abadi & VanderVeer, 2020; Audenhove *et al.*, 2020). Furthermore, the impacts of the pandemic on mobility and transportation systems could present an opportunity for transit authorities to redesign mobility systems to focus more on MaaS (Serafimova, 2020; SkedGo, 2020). However, the pandemic has likely had a negative impact on the scalability of MaaS development over the short term because of the collapse in demand for public transit and shared mobility (Audenhove *et al.*, 2020). The pandemic may also spur government to develop policies and regulations for the use and sharing of transportation data (Audenhove *et al.*, 2020). Indeed, integrated mobility systems that provide users with data about public transit crowding levels, transit time, and frequency of cleaning could help users better manage their transportation in a post-COVID world (SkedGo, 2020). The pandemic could also motivate governments to address socioeconomic, racial, and gender inequalities that are mediated through transportation, which have been exacerbated by COVID-19 (Audenhove *et al.*, 2020; Mayaud, 2020). As noted above, investments in infrastructure for electric vehicles could be leveraged to support economic recovery and reduce transportation-related emissions.

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CCA Reports of Interest

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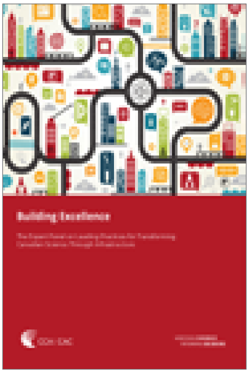

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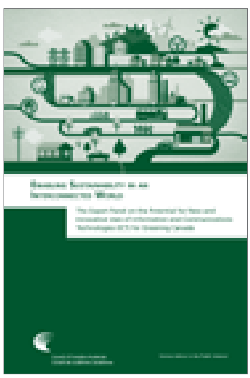

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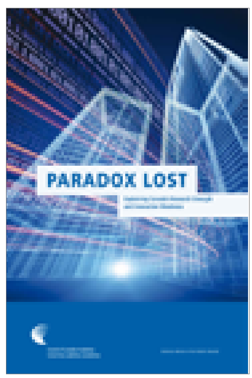

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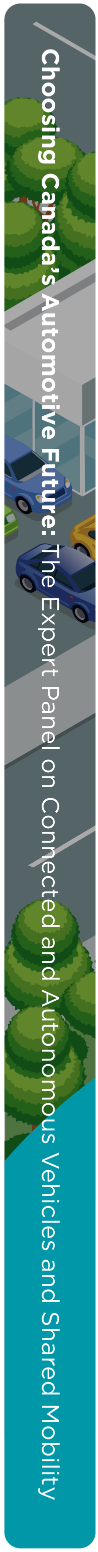

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