A FUTURE WITH AUTONOMOUS VEHICLES:
Issues, the potential for research topics, and a personal perspective

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There is a large quantity of research, reports and media articles on the subject of autonomous vehicles. While autonomous vehicles are just one component of the technological developments of artificial intelligence, they are currently generating the most interest. This survey begins with a broad taxonomy of the potential for autonomous vehicles in transportation, and then focuses on the specific issues associated with the advent of fully autonomous cars on public streets and highways.

I INTRODUCTION

Autonomous vehicles are in various stages of consideration throughout transportation:

- *Ai*r: Fixed-wing aircraft, helicopters and drones may all become fully autonomous. For fixed-wing commercial aircraft this is already a possibility, but public opinion at present does not encourage the prospect of pilotless passenger aircraft. This may change once the public becomes comfortable with fully autonomous cars on the road [i] ;
- *Rail*: Fully autonomous passenger locomotives such as those used in the Copenhagen Metro, and the heavy haul freight locomotives of Rio Tinto in the Pilbara iron ore region in western Australia, are already in operation. Train technology may advance in the future, including such innovations as the hyperloop, to become fully autonomous – particularly for passenger transportation – but the problems associated with the introduction of positive train control on the US predominantly freight railroads, and the objection of rail unions to even one-person train crews, may restrict freight developments over the medium term [ii] ;
- *Marine*: At present no fully autonomous ships are in operation, but there are definite plans for such ships by 2025, according to a report by Rolls-Royce [iii] ;
- *Off Road, private road, and facilities:*
    - Fully autonomous trucks and buses are already in operation in large factories, distribution centres, and on industrial sites such as mining, construction, and the Canadian oil sands [iv]
    - A number of other vehicle types would not, at first glance, appear to be suitable for fully autonomous operation – snowmobiles, all-terrain-vehicles, racing cars and motorcycles on race tracks, lawnmowers, wheelchairs on pavements for the disabled. Such vehicles do exist – sometimes in robotic form– but there will probably only ever be niche markets for such products [v]
- *On public roads and highways:* Autonomous systems for on road use have been categorized by the international Society of Automotive Engineers (the standards adopted by Ontario) and the US National Highway Traffic Safety Administration. For present purposes it will be sufficient to refer to L3 (Conditional Automation), L4 (High Automation: vehicles are designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip but are limited to the "operational design domain" of the vehicle—meaning it does not cover every driving scenario.) and L5 (Full Automation: the vehicle's performance to equal that of a human driver, in every driving scenario—including extreme environments like dirt roads, snow or fog). In this paper fully autonomous will refer to L4 or L5 as appropriate.

- *Trucks – on highways and city streets*: The current state of development is comprehensively reviewed in a recent report by the American Transportation Research Institute [vi] . At present L3 trucks do exist in small numbers, L4 trucks are in the pilot stage of development, and fully autonomous L5 trucks do not exist, and may not be developed for quite some time. It is anticipated that autonomous trucks will operate over highways and in urban areas, and might be platooned (or convoyed) on highways. It is likely that even for L5 trucks, a person would be required on board (although not necessary) to conduct critical freight movement tasks other than driving. Numerous issues remain concerning the technology, infrastructure, regulation and liability – for example, whether there will be truck-only lanes on existing highways or new truck-only highways;
- *Buses – transit, school and intercity*: According to the American Bus Association [vii] L5 local transit buses are now operating in selected cities in the US, UK, Singapore, Netherlands, China, and Finland. School buses are also under consideration, but there do not appear to be any fully autonomous intercity buses at time of writing;
- *Emergency vehicles – fire, police and ambulance*: The need for speed and priority would suggest a continuing need for human drivers, and/or specialized technology;
- *Motorcycles and pedal bicycles*: Google is testing a fully autonomous driverless motorcycle – the purpose of such machines is unclear, but could include small parcel delivery in cities. Despite several humourous fake news stories, fully autonomous pedal bikes are unlikely.

The above taxonomy is not exhaustive, and given the fast pace of developments, may not be fully up-to-date by mid-2017. Nevertheless, it does identify a wide range of possible research areas for Canadian transportation researchers in the universities, the private sector and governments. The balance of this survey paper focuses on a future with L4/L5 cars and taxis on public roads and highways.

II FULLY AUTONOMOUS CARS AND TAXIS ON PUBLIC ROADS AND HIGHWAYS

There are different views on the timing of the technology. Some experts suggest, as recently reported in Automotive News [viii], that L5 fully autonomous cars will not arrive for a long time – they are a decade or more away, despite industry comments to the contrary. Moreover, it may be decades before a vehicle can drive itself safely at any speed on any road in any weather. However, L4 automated driving at low speeds in good weather may be happening by 2021. In contrast, Tesla announced on October 19, 2016 that "*all Tesla vehicles produced in our factory – including Model 3 – will have the hardware needed for full self-driving capability at a safety level substantially greater than that of a human driver*". Whether this is L4 or L5 is not stated, but on October 20, 2016 Futurism [ix] states all new Tesla cars "*will have L5 autonomy*". Rather than take a position on timing, this paper will focus on a future with L4/L5 fully autonomous cars – whenever that arrives.

2.1 Technology

The details are far beyond the scope of this paper (or author), but a simple summary provides a sense of what technology is required for L5 autonomous cars [x] :

- *Cameras*. To read signs, lane markings and other features of the environment;
- *Laser Illuminating Detection and Ranging (LIDAR)*. This is used to build a 3D map and allow the car to "see" potential hazards. It works by bouncing a laser beam off of surfaces surrounding the car in order to accurately determine the distance and the profile of the object. It is usually roof-mounted;

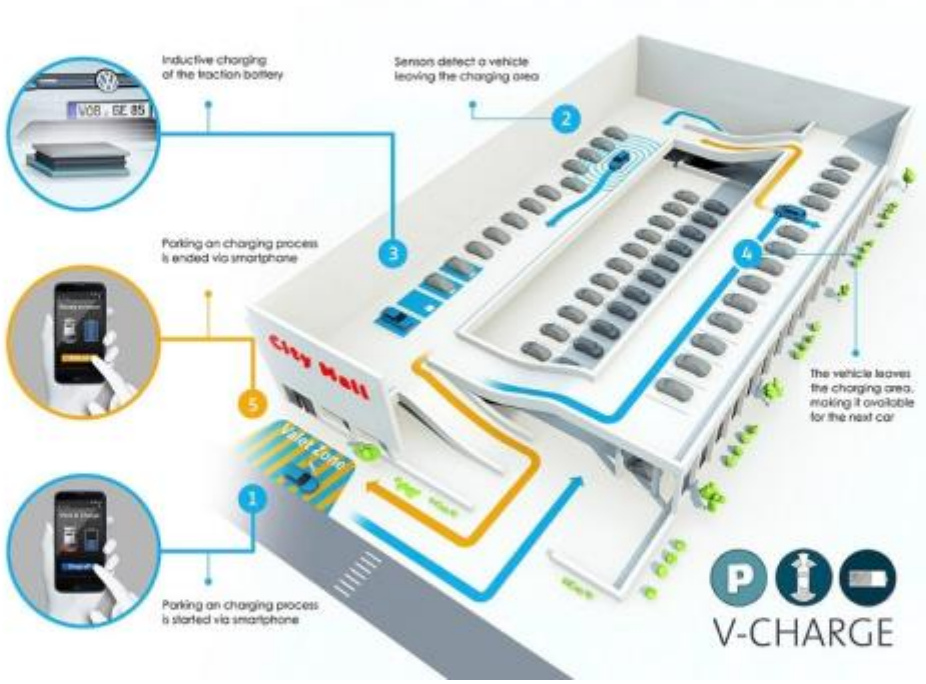
- *Radar*. While LIDAR is good for accurately mapping surroundings, its flaw is its inability to accurately monitor the speed of surrounding vehicles in real time. This is where bumper-mounted radar units come in. They work in conjunction with other features on the car such as inertial measurement units, gyroscopes, and wheel encoders to allow the car to avoid impact by sending a signal to apply the brakes, or move out of the way when applicable.
- *Sensors*. While the cameras, LIDAR, and radar are used for obstacle and environment monitoring, sensors are used extensively to understand what is happening with the car itself. In addition to navigating the roads, the autonomous car also needs to monitor itself to know that it is not traveling over the speed limit or if something is wrong with the car and it has to pull over;
- *Communications*. Autonomous cars need reliable, high-speed two-way data communications equipment for navigation, vehicle-to-vehicle and vehicle-to-infrastructure communication, and content reception. This includes antennas, Dedicated Short Range Communication (DSRC), 5G LTE (long-term evolution) receivers – a high speed communication platform commonly used in smartphones– and differential GPS receivers;
- *Human-machine interface (HMI)*. This refers to the combination of systems in the interior of the vehicle, including the infotainment/entertainment system, instrument panel, and controls that act as an interface between the car and its occupants. It is comprised of an array of in-cabin sensors, screens, and controls, and is one of the most complex elements within an autonomous car. The HMI needs to be aware of the internal environment of the car, in case of emergency situations, and in exceptional cases needs to alert the occupants that it needs to be manually controlled or that it is pulling over;
- *Domain controller***.** The domain controller functions as the hardware "brain" of the autonomous driving system. It acts as the crossover between the input and output systems of the car by receiving signals from the various cameras, LIDAR, radar, and sensors, determining what action is to be taken and then communicating with the car's drivetrain to execute the necessary actions. The domain controller is also likely to be where the software brain / operating system of the car resides, and needs highly detailed 3D maps of the area in which the car operates;
- *Motion control systems/actuators/mechatronic units*. Once the domain controller has decided what action is to be executed based on inputs from the sensing units, it passes instructions to mechatronic units/actuators which physically control the drivetrain components, such as the steering wheel, throttle, brakes, suspension, etc.

These systems have built-in redundancies to ensure safety in the event of a component failure. It is estimated that, somewhat surprisingly, the technology costs for a fully autonomous car will be less than $10,000, and perhaps much less once the industry scales up [xi] .

2.2 Energy for Fully Autonomous Cars

Industry commentary suggests the most likely energy source for the fully autonomous car will be electricity from batteries [xii]. However, it is not a foregone conclusion, and the cars may also be hybrid, fueled exclusively by gas, diesel, or propane (in the case of taxis), or even use hydrogen fuel cells, as Toyota is developing. Gas, diesel and propane have existing fueling station networks, but networks for hydrogen refueling or electric charging stations need to be rolled-out, or alternatives found.

In 2016 the range of a fully charged electric vehicle was 200-300 miles (much less in cold weather), and improved plug-in technology could provide a recharge of 250 miles of range in about 15 minutes. Electric cars can therefore be used in an urban setting without serious range concerns, by charging overnight at home. Long-distance travel is more challenging due to limited charging infrastructure. However, alternatives are being researched: for example, Volkswagen has proposed a V-Charge concept, illustrated overleaf. It depends on wireless charging pads installed in parking spots. After leaving your car by the entrance, it would take itself to the nearest available charging spot and begin filling the battery. When it is finished, it would move so the next car would have a place to charge.



Tesla has proposed the idea of swapping out the battery at a charging station instead of recharging. The project is on hold, but might catch on once there are many more autonomous cars on the road.

The economic benefits of fully autonomous cars will be addressed in a later subsection, but, for now, it should not be automatically assumed that air emissions, including greenhouse gases, will be reduced with the advent of electric fully autonomous car fleets [xiii]. Given the balance of commentary, the rest of this paper will assume fully autonomous cars are electric – especially as some cities are beginning to discriminate against fossil fuel cars in favour of electric.

2.3 Automotive Industry: Manufacturing, maintenance and repair, liability and Insurance

The autonomous car industry is composed of traditional carmakers – GM, Ford, Chrysler, Toyota, Honda, BMW, Volkswagen etc. – new entrants such as Tesla motors, tech companies such as Google, Apple and Blackberry, and parts suppliers – Magna, Delphi etc. How the industry will evolve with the advent of electric autonomous cars is the subject of intense speculation, but it is expected to be the biggest technological disruption the car industry has faced in decades [xiv].

It is likely that some traditional carmakers will design and fully manufacture electric autonomous cars, including the car body, the autonomous technology, and the infotainment/entertainment content in the car. In contrast, others may adopt an asset-light, outsourced model, in which the firm designs and sells an autonomous car under its brand and distribution network but outsources the component parts. This could include sourcing the engine, transmission, battery, and other interior/exterior components from parts suppliers, and using software and autonomous capability developed by technology suppliers. Business models in between these extremes are also possible. Interestingly, both Google and Apple have recently dropped plans to build cars in favour of concentrating on the technology and software.

The cars themselves are expected to indicate when routine maintenance is required. More owners are expected to use traditional car dealerships, rather than independent repair shops, due to the safety-critical nature and complexity of autonomous technology. Significant repairs may be required less frequently, but could be costlier due to the car's increased complexity.

On the matter of liability and insurance for autonomous cars – when the owner may not be driving or there may no occupants at all – the Insurance Institute of Canada [xv] indicates that *"personal liability for most collisions will begin to shift to include a mix of personal and product liability"*. Moreover, *"Insurance coverage is presently available for aircraft, trains, ships, and other vehicles with substantial automation. Insurance coverage for these automated vehicles could provide guidance for policies to cover self-driving cars. Such coverage would likely be based on product liability. Perhaps a greater challenge will be to secure regulatory approval. Primary coverage may focus on the vehicle manufacturer, but some residual coverage will be needed for drivers if the first self-driving vehicles have the capacity for drivers to assume control. The application of manufacturer liability will be easiest to put into practice for vehicles that are fully self-driving, with no capacity for human drivers to take control."*

2.4 Government Involvement: Safety, Regulation, and Infrastructure - highways, roads, parking

According to a comprehensive report by the US RAND corporation [xvi] "*careful policymaking will be necessary to maximize the social benefits that this technology will enable, while minimizing the disadvantages*". In Canada, the Canadian Autonomous Vehicle Centre of Excellence [xvii] has issued a White Paper with recommendations for governments, including harmonization between Canadian jurisdictions and the US, while noting that Canada is behind the rest of the G7 in planning. The Canadian Council of Motor Transport Administrators has a working group looking at the regulation of autonomous vehicles – Transport Canada and the provincial and territorial transportation agencies are all members. Also, Transport Canada is participating in international standards development activities, but the extent and complexity of these issues can best be illustrated by the US Federal Automated Vehicles Policy [xviii] issued in September 2016.

The division of standards and regulatory responsibilities in the US are broadly similar to those in Canada. Federal responsibilities include:

- Setting Federal Motor Vehicle Safety Standards (FMVSS) for new motor vehicles and motor vehicle equipment. Manufacturers must certify compliance before they sell their vehicles;
- Enforcing compliance with the FMVSS;
- Investigating and managing the recall and remedy of non-compliances and safety-related motor vehicle defects and recalls on a nationwide basis;
- Communicating with and educating the public about motor vehicle safety issues; and
- Issuing guidance for vehicle and equipment manufacturers to follow, such as the Vehicle Performance Guidance for highly automated vehicles – L3, L4 and L5

State (Provincial) responsibilities include:

- Licensing (human) drivers and registering motor vehicles in their jurisdictions;
- Enacting and enforcing traffic laws and regulations, including distracted driving laws;
- Conducting safety inspections, where States (Provinces) choose to do so; and
- Regulating motor vehicle insurance and liability.

The US Vehicle Performance Guidance for highly automated vehicles covers the areas in its safety assessment as indicated in the Table overleaf.

Data Recording and Sharing	Privacy	System Safety	Vehicle Cybersecurity
Human Macine Interface	Crashworthiness	Consumer Education and Training	Registration and Certification
Post Crash Behaviour	Federal/State/local laws	Ethical Considerations [1]	Operational Design Domain [2]
Object and Event Detection and Response - crash avoidance		Fall Back (minimal Risk Condition)	Validation Methods
[1] Software decision rules that favour car occupants over other persons			
[2] Geographical location, roadway type, speed, day/night, weather conditions			

The complexity of all these issues is beyond the scope of this paper, but offers a wide range of possible research areas for Canadian transportation researchers. There is a report [xix] with interesting commentary on the ethical issues, as well as the measurement of system safety. It is also important to note that autonomous vehicles can create positive externalities – crash reduction, declines in fuel consumption, increase in mobility, changes in land use, more difficulty to hijack for a terrorist attack – not all of which accrue to vehicle owners but to the public generally. Some have suggested that a combination of subsidies and taxes might be useful to internalize these externalities and achieve a socially optimal outcome.

The advent of fully autonomous cars may not require significant changes to public infrastructure – highways and roads – although investment may be needed in vehicle-to-infrastructure communications, better lane markings, dedicated autonomous car lanes, coils embedded in the road at intersections to charge batteries, or more roundabouts. Existing highway capacity may increase, due to fewer accidents and vehicles being able to drive closer together or "platooning" [xx]. There may also be a decreased need for proximate parking, as an autonomous car could simply drop off its passenger and drive away to satellite parking areas. One estimate [xxi] concluded that some 31 percent of space in central business districts of major US cities is devoted to parking. Sharing programs may also decrease the rate of car ownership. In either event, fewer parking spaces would be necessary and would permit greater land development of cities.

2.5 Markets for Fully Autonomous Cars

Obviously, fully autonomous cars may be owned by individuals for their private use – as cars generally are today – but maybe nor for quite some time. However, other possibilities exist. Fleets of such cars might be owned and operated by the next-generation of car rental and taxi companies, or ride-sharing companies like Uber and Lyft, perhaps without drivers at all. This is generally referred to as Transportation-as-a-Service (TaaS).

Several commentators [xxii] suggest that the roll-out of fully autonomous cars will begin with fleets providing TaaS in selected cities. Their reasoning is as follows:

- The very detailed 3D maps required [xxiii] will be made first for selected city centres. To avoid weather problems such as snow or fog, map makers may start where the weather is not inclement – which may slow developments in Canada. From city centres the mapping will probably be extended to the suburbs and exurbs of large cities, then to the major highway networks linking cities across the continent, and finally to encompass lightly populated rural areas;
- First-mover fleet operators in city centres may be able to capture network effects;
- Fleet operators will be better able to monitor, maintain and repair their cars in a compact city centre;
- Fleet operators may well find such TaaS profitable, without the cost of drivers and a lesser risk of serious accidents with slower speeds.

An important question is whether or not these fleets would involve ride-sharing, and appear more like transit. Ride-sharing would likely reduce the number of cars on the road [xxiv], and thereby reduce congestion. However, one of the anticipated benefits of fully autonomous cars is the opportunity to work while traveling, which might not be so easy when ride-sharing. Moreover, as is the case today, households may prefer to own their autonomous car for convenience and prestige.

The issue of congestion is a matter of debate [xxv]. If ride-sharing becomes popular then congestion will likely be alleviated. If it does not, then the size of fleets providing TaaS that would be needed to handle the demand from millions of individual commuters during the morning and late afternoon traffic peaks in major cities, may be prohibitive. In this case, congestion may remain the same, or even increase if commuters send their cars back home empty rather than park them downtown. Further analysis along these lines is at present speculation, but worthy of further attention by transportation researchers.

2.6 Economic and Environmental Impacts, Benefits and Costs

The Conference Board of Canada [xxvi] has quantified the economic benefits of autonomous cars in Canada, following an earlier analysis from Morgan Stanley [xxvii] regarding the US. For the results see Exhibit 1.

EXHIBIT 1		US - US$		CANADA
	BASE	HIGH	LOW	
		(US$)		(CDN$)
ASSUMPTIONS				
Fuel price per gallon/litre	$4	$6	$3	$1
Improvement in fuel efficiency	30%	50%	15%	10%
Statistical value of a life - $millions	$7.9	$9	$6	$15.57
Median income per hour	$25.03	$32.50	$19.00	$24.00
Percent of time in car at work	30%	50%	10%	66.7%
ACCIDENT SAVINGS - $billions	$487.8	$520.4	$431.6	$37.4
PRODUCTIVITY GAINS FROM WORK - $billions	$506.9	$1,096.9	$128.3	$19.9
FUEL SAVINGS				
Value saved from reducing congestion - $billions	$11.0	$16.5	$8.3	
Value saved from increased fuel effiency - $billions	$160.7	$401.7	$60.3	
TOTAL VALUE OF FUEL SAVINGS - $billions	$171.7	$418.3	$68.5	$2.6
PROUCTIVITY GAINS FROM CONGESTION REDUCTION - $billions	$137.9	$179.1	$104.7	$5.0
TOTAL ANNUAL SAVINGS - $billions	**$1,304.3**	**$2,214.6**	**$733.1**	**$64.9**

The figures in Exhibit 1 represent annual estimates with a 100% roll-out of autonomous cars. Details of the calculations are in the reports, but the following points may be noted:

- Accident savings are large, assuming 80-90% savings in the cost of injuries and fatalities. These estimates are highly dependent on the assumed statistical value of life, which is particularly high in the Canadian figures;
- Productivity gains from work while in an autonomous car are also large, and depend upon the imputed value of time;
- Fuel savings are relatively smaller. However, if fully autonomous cars are electric, these calculations are incorrect. Instead of valuing the reduction in fossil fuel use, they should be estimating the net benefit of replacing all fossil fuel use with electricity [xxviii] . More research is called for here;
- Productivity gains from congestion reduction are also relatively small, or may not occur at all as indicated in the earlier subsection. Moreover, changes in the volume of overall travel with the advent of autonomous cars is also a matter of debate.

These attempts at quantification are worthwhile and heroic, and do give an idea of the relatively important benefits of accident reduction and the productivity gained from working while traveling. Other potential benefits [xxviv] not included in the analyses are reduced driver stress, increased mobility for the disabled and the elderly, and environmental benefits from air emission reductions resulting from a shift from fossil fuel to electricity – although this may not be universal if coal is used for electricity generation.

Apart from research and development and implementation costs, fully autonomous cars have some important indirect or collateral costs, including considerable market disruption, significant decline in the demand for fossil fuels, loss of employment in a range of sectors, and the need to be cautious in the further development of public infrastructure.

III CONCLUSIONS – And a personal perspective

This survey paper is a work-in-progress, and may be out-of-date very quickly. Nevertheless, I hope it gives a sense of the issues in a future with autonomous cars, and provides potential research topics for Canadian students and researchers in transport.

Five points may be identified as conclusions drawn from the paper:

1. L4 rollout in selected cities with benign weather will likely occur within the next 5 years, but L5 roll-out will probably take much longer;
2. Whether L4/L5 cars will increase existing road capacity, reduce congestion, and have a positive impact on the environment is currently uncertain and needs further research;
3. Whether initial rollout will involve individual ownership and/or TaaS - either with individual or shared services - is also uncertain and needs more assessment of the relative speeds of adoption and their implications;
4. Governments can significantly promote or impede rollouts through regulation or infrastructure changes – for example, by taxing movements of empty cars (recently proposed in a Massachusetts Bill together with a requirement to be electric) or requiring L5 cars to have a steering wheel;
5. Canada may need to accelerate its involvement with autonomous cars, perhaps including R&D of autonomous cars in winter weather.

Of particular interest to researchers may be point 2 - the likelihood of existing road capacity increases, and the impacts on congestion and the environment. On a more personal note, I have two concerns:

- Who will be allowed to drive alone in a fully autonomous car? Unaccompanied children with seat belts? Adults impaired by alcohol or drugs? Current public opinion surveys have suggested that the public is divided fairly evenly on the matter of unaccompanied children, while enthusiasm for autonomous cars falls significantly when it is suggested that impaired adults may be forbidden as sole occupants;
- On a larger matter, several commentators – including Elon Musk – have suggested that once fully autonomous cars are rolled-out, the public may be banned from driving on public highways and roads. One wonders what antique and sports car enthusiasts, those who ride Harley-Davidson motorcycles, those who drive for pleasure, “fahrvergnügen” as they say in Germany, or even pedal bicyclists and pedestrians will have to say on the matter?

Such a ban, for the sake of increased safety, would be reminiscent of the ban on smoking in public places, or the continual push in the US to limit gun ownership, and would be another potential item of dispute for the public at large. However, to finish on a note of optimism: by 1950-75, few if anyone was concerned that they were not driving horse-and-carts on the public thoroughfare, which was ubiquitous in 1900. So perhaps in 50-75 years, the younger generations will have grown up without ever having driven, and so would not be concerned with its absence in their lives.

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[i] For further details see, for example: “Planes Without Pilots”, John Markoff, New York Times, April 6, 2015; “Inside DARPS’s plan to make old aircraft autonomous with robot arms” Jack Srewart, November 2, 2016, www.wired.com; and “Towards the end of Pilots” by Arnold Reiner, The Atlantic, Mar 3, 2016.

[ii] For further details see for example: “List of automated urban metro subway systems”, from Wikipedia; “Rio Tinto invests US$518 million in autonomous trains for Pilbara iron ore rail network in Western Australia”, Rio Tinto February 20, 2012;”, and “Hyperloop”, from Wikipedia.

[iii] For further details see: “Autonomous Ships: The next step”, Rolls-Royce, June 21, 2016; and “The Autonomous Ship”, MUNIN, 2016.

[iv] For further details see for example: “Komatsu unveils Autonomous Haulage Vehicle, a mining truck that doesn’t even have a cab”, Wayne Gratson, Equipment World, September 29, 2016.

[v] For further details see: “Bombardier’s new concept to eliminate hiking for backcountry skiers”, Charles Bombardier, Globe and Mail, December 13, 2015; “Sikorsky’s Autonomous ATV”, Zachary Coffey, GAS2, June 10, 2014; “Revealed: the world's first driverless, autonomous racing car”, Alex Robbins, The Telegraph, August 23, 2016; “Google testing the autonomous motorcycle waters in California”, Jeremy Korzeniewski, Auto Blog, August 13, 2014; “Does a Robotic Lawn Mower Really Cut It?”, Sal Vaglica, Wall Street Journal, April 12, 2016; “Autonomous wheelchair could change the lives of motor-impaired users”, Luke Dormehl, Digital Trends, September 15, 2016.

[vi] “Identifying Autonomous Vehicle Technology Impacts on the Trucking Industry”, Jeffrey Short and Dan Murray, American Transportation Research Institute, November 2016.

[vii] “The Cutting Edge: Autonomous Buses Coming to a Road Near You”, Melanie Hinton, American Bus Association, July 27, 2016.

[viii] “Fully autonomous vehicles won't arrive for a long time”, Richard Truett, Automotive News, October 10, 2016.

[ix] “Elon Musk: Every Tesla Car Will Be Fully Autonomous by 2017”, June Javelosa and Kristan Houser, Futurism, October 20, 2016.

[x] For further details see: “Autonomous Cars**:** Self-Driving the New Auto Industry Paradigm”, Morgan Stanley Blue Paper, November 6, 2013.

[xi] “Prepare for the Electric car revolution”, Stephen Wilmot, Wall Street Journal, December 14, 2016.

xii “Eyes on the Road”, The Economist, December 24, 2016.

[xiii] When electricity is generated by coal fired utilities, on road use by an electric car may result in more air emissions that a highly fuel efficient gas or hydrogen fuel cell car. This issue is very dependent upon the specifics of the circumstances: for example, the Environmental Impact Analysis of the Keystone pipeline project in the US determined that air emissions from rail were lower than pipeline due to the significant electricity needed to power the pumps to push oil though the pipe, and the electricity in the upper mid-west is derived from coal utilities

[xiv] For more details see, for example: “Autonomous Cars Self-Driving the New Auto Industry Paradigm”, Morgan Stanley Blue Paper, November 6, 2013; and “ Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry”, McKinsey and Company, January 2016.

[xv] “Automated Vehicles: Implications for the Insurance Industry in Canada”, The Insurance Institute of Canada, 2016.

[xvi] “Autonomous Vehicle Technology: A Guide for Policymakers”, RAND corporation, 2016.

[xvii] “Preparing for Autonomous Vehicles in Canada: A White Paper Prepared for the Government of Canada”, Canadian Automated Vehicles Centre of Excellence (CAVCOE), December 16, 2015.

[xviii] “Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety”, National Highway Traffic Safety Administration, September 2016.

[xix] “Top misconceptions of autonomous cars and self-driving vehicles”, Alexander Hars, Inventivio, September 30, 2016.

[xx] “ Highway Capacity Impacts of Autonomous Vehicles: An Assessment”, Abdul Pinlari et al, Center for Urban Transportation Research, University of South Florida, November 2013.

[xxi] “The High Cost of Free Parking”, Donald Shoup, APA Planers Press, 2005.

[xxii] Ibid

[xxiii] “Uber and Google race against car firms to map the world's cities”, Hal Hodson, New Scientist, September 28, 2016.

[xxiv] For more details see: “Uncongested Mobility for All: New Jersey’ Area wide a Taxi system”, Kornhouser, Princeton University, 2013 , or “The Impact of Car-sharing on Household Vehicle Ownership”, Eliot Martin and Susan Shaheen, Access, Spring 2011.

[xxv] “Autonomous Cars Likely to Increase Congestion”, Michael Barnard, Clean Technica, January 17, 2016.

[xxvi] “Automated Vehicles**.** The Coming of the Next Disruptive Technology”, Conference Board of Canada, 2015.

[xxvii] Ibid

[xxviii] A complete switch to electric cars would merely be a challenge to electric utilities in the US, by boosting demand by 25% when there is existing overcapacity to maintain reliability, according to “ A Charged Way to Play Electric Vehicles”, Spencer Jakab, Wall Street Journal, December 21, 2016. Also “Electric Cars Are Not Necessarily Clean”, David Biello, Scientific American, May 11, 2016.

[xxviv] “Autonomous Vehicle Implementation Predictions: Implications for Transport Planning”, Todd Litman, Victoria Transport Policy Institute, November 25, 2016.