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MASTER'S THESIS

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Preface

This master marks the final chapter of the master program in Industrial Economics at the University of Stavanger.

During my time at the master program I was introduced to a wide range of topics within my specialization in Technology Management and Entrepreneurship. Finding a topic for a master thesis was interesting and challenging, but finally deciding on a topic was liberating.

First and foremost I express sincere appreciation to Dr. Dina Zhenisovna Kairbekova for participation on her field of research (Department of security, economics and planning) and for excellent supervision. I am truly grateful not only for her aid in deciding a topic for the thesis but also for helpful information during meetings.

Further I want to acknowledge my brother Michael Ojiaku (Eaton Corporation) for being an examiner for this paper and for providing valuable and constructive feedback for improving this paper.

Gratitude to Hemn Ahmed for providing template for this thesis with a kick start introductory tutorial to LaTeX .

I want to extend my special thanks to friends and family for all encouragements and support throughout my studies.

Finally, I want to thank God for strength and guidance throughout this masters program.

Abstract

Advancement in autonomous driving technology has created numerous opportunities for safer, smarter and more sustainable mobility to solve most of the problems that urbanization is causing on the roads. Autonomous driving technology is an emerging application of automotive technology. Vehicles with this feature can recognize the scene, plan the path, and control the motion by themselves while interacting with drivers. Although they receive considerable attention, artificial intelligence components of autonomous vehicles are not accessible to the public but instead are developed as proprietary assets.

The objective of this thesis is to research how artificial intelligence in vehicles can help solve traffic congestion and what other benefits it can produce in our daily lives. There is a lack of knowledge on how the AI will disrupt and which policy strategies are needed to address such disruption. The aim is to determine where we are, where we are headed and what likely impacts this disruptive technology can do to traffic congestion. The methodology is based on a systematic review of existing research and evidence, to help understand the capability, impact and limitations associated with autonomous vehicles.

The review reveals the trajectories of technological development of autonomous vehicles, disruptive effects caused by such development, improvements to the current state of autonomous vehicles. The paper also reveals what technology is needed to solve traffic congestion and what is needed to meet that objective.

List of abbreviations

AV	Autonomous vehicles
AI	Artificial intelligence
GPU	Graphics Processing Unit
FPGA	Field-programmable gate array
ASIC	Application Specific Integrated Circuit
PEV	Plug-in electric vehicles
GHG	Greenhouse gas
EV	Electric vehicles
CV	Combustion vehicles
FI	Fuel intensity
EI	Energy intensity
UI	Use intensity
VMT	Value of miles travelled
V2V	Vehicle to vehicle
V2I	Vehicle to infrastructure
EDR	Endpoint detection and response
GNSS	Global navigation satellite systems

RCA	Radio corporation of america
IoT	Internet of things
ADS	Automated driving systems
ACC	Adaptive cruise control
ANS	Automotive navigation system
GPS	Global positioning system
TMC	Traffic message channel
OEM	Original equipment manufacturer

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Chapter 1

Introduction

1.1 Objective of the thesis

The objective of this thesis is to identify if development of autonomous vehicles will bring improvements to traffic congestion, climate change and mobility.

As stated in (Hristozov, 2020)[1] autonomous vehicles are starting to become a real possibility in some parts of industry. Agriculture, transportation and military are some of the examples. The day when we are going to see autonomous vehicles in everyday life for the regular consumer is quickly approaching. Many of the operations that vehicles have to perform are based on sensor information and some AI algorithms. Vehicles need to collect data, plan their trajectory and execute the trajectory. These tasks, especially the last two require non-traditional programming approaches and rely on machine learning techniques, which are part of AI.

There are many tasks for autonomous vehicles that are still presenting significant challenges and require sophisticated approaches. Replacing the cognitive and motor abilities of a human is not easy and will continue to be work in progress for years to come. There are different tasks that AI needs to solve so that we achieve reliable and safe autonomous driving.(Hristozov, 2020)[1]

1.2 Climate effects of road congestion

Reducing road congestion is a very important topic. With the increasing traffic congestion, the release of green house gases increases proportionally. And this leads to the undesirable global warming phenomena that the world is trying to tackle.

Climate change is already affecting global agriculture, forestry, land use, water resources and biodiversity. IPCC an intergovernmental body of the United Nations reviews evidence that indicate that due to the climate change:

- Crops and pests are migrating toward the poles;

- Livestock grazing land is changing in carrying capacity;

- Forests are facing threats from increased fire incidence, insect outbreaks and windstorms;

- Water supplies and snowpack are being altered, changing the dynamics of water use;

It is virtually inevitable that climate change will continue to have significant effects in these and other ways in the coming decades and beyond. Atmospheric CO_2 concentrations are reaching levels that will almost certainly cause a substantial degree of climate change and entail adapting to the resultant changed climate.(Cossia, 2010)[2]

Changes in the climate have also been observed and reported by the IPCC indicating that:

- Temperature has risen by about 1 degree centigrade since 1900;

- Rainfall patterns are changing with droughts occurring in much of the subtropics and wetter conditions in the high latitudes;

- Rainfall is becoming more concentrated;

There is a robust scientific consensus that humans are exerting a significant and growing influence on the climate largely though the emission of greenhouse gases. Global atmospheric concentration of the most abundant, carbon dioxide, has increased from a pre-industrial value of about 280 parts per million (ppm) to 345 ppm in 1985 and on to 390 ppm in February 2010; significant increases are also observed in the atmospheric concentration of methane and nitrous oxide.(Cossia, 2010)[3]

1.3 Factors causing traffic congestion

According to (Falcocchio and Levinson, 2015) [4] congestion is due to three general causes: (1) the inability of the streets to hold a sufficient number of vehicles and to process them at an adequate speed, (2) the inclusion of elements in the traffic stream which hamper its free flow, and (3) the improper or inadequate direction and control of traffic.

Today the causes of traffic congestion are more specifically known and include (1) large concentrations of demand in time and space—including temporal surges in travel demand on roadways of generally constant capacity physical, operational, and design deficiencies that create bottlenecks, (2) traffic demand that exceeds roadway capacity, and (3) physical and operational bottlenecks. Congestion generally increases with city size. This happens because activity concentrations are larger, and travel distances are longer as cities grow. Economists view chronic congestion as a pricing-induced problem. They argue that the absence of marginal cost pricing contributes to congestion because average cost pricing makes road use more attractive than it would be if prices would rise with congestion.(Falcocchio and Levinson, 2015)[4]

Figure 1.1: *Traffic congested city.*
[5]

1.4 Novelty of research

Artificial Intelligence in vehicles are in the early stages of research and development. Numerous companies in China, Europe and the US are in a race to perfect this technology. What makes this a novel research is that no government or company have perfected the implementation of artificial intelligence in vehicles. To produce self driving trucks, cars or to implement technology like AI cloud services or other software technology that can help the vehicle understand the road, weather, patterns and other factors that can help reduce road congestion.

As stated by (Bayern, 2019)[6] most major autonomous vehicle companies have carried out successful tests, but many autonomous vehicles still have a human present in the vehicle in case of error.
The technology is not done. It's not ready for commercial applications. The technology simply does not yet exist to support completely autonomous vehicles, which can navigate highways, congested metroplexes, or harsh driving conditions.
Michael Ramsey, senior research director of automotive and smart mobility at Gartner, said that in the next few years, we are realistically "more likely to see shuttles and semi-public transportation in the form of slow-moving, granny-like vehicles that are operating in cities and dense urban areas. It may be that they operate in protected or semi-fixed routes for some time to come."
Along with technological limitations, safety is another major barrier to both development and public adoption.
"Delivering self-driving cars at scale isn't just about winning the tech race, it's about winning the tech race and the trust race". "When you're working on large-scale deployment of mission-critical safety systems, the mindset of 'move fast and break things' doesn't cut it."
While fully autonomous vehicles still have a long road ahead of them, some companies are using available technology to make waves in the industry.

1.5 Method

The research approach of this thesis is primarily that of a qualitative research. As explained above, the development of autonomous vehicles is in it's early stages. Therefore, there is limited imperial and scientific data on earlier research because it has not been widely adopted. This thesis is meant to get in-depth insights into the problem and generate new ideas for further research.

The technical aspect of autonomous vehicles was explored by studying academic research, while theories about the benefits and limitations of autonomous vehicles were explained with in-depth analyses based on practical data.

The data was collected mainly by means of observations, such as reading of previous publications on the topic and watching videos published by researchers and automotive companies. Therefore, the thesis is considered a systematic review, which is an appraisal and synthesis of primary research papers using a rigorous and clearly documented methodology in the search strategy and as well the selection of studies. It also analyses and studies the available literature in order to give answers to the research questions.

Chapter 2

Background

2.1 Urbanization and Mobility

This master thesis focuses on autonomous vehicles and how these vehicles can provide sustainable mobility and disruptive mobility solutions in urban areas. It requires knowledge about autonomous vehicles to study the impact they can have on society. There are numerous uncertainties surrounding autonomous vehicles, but it is necessary to understand how we could integrate them into the existing traffic system. The challenges and limitations they impose on the transportation system are also crucial to understand, as well as the benefits.

According to Mcdonald et al. (2014)[7] a recent global assessment by hundreds of scientists, the Cities and Biodiversity Outlook (CBO) examined how the coming massive global urban growth will interact with the natural world. By 2030, there will be almost 2 billion new urban residents, and this rapid urban growth has significant implications for the fate of human society and the natural world. On the figure below the UN projections of urbanization is shown.

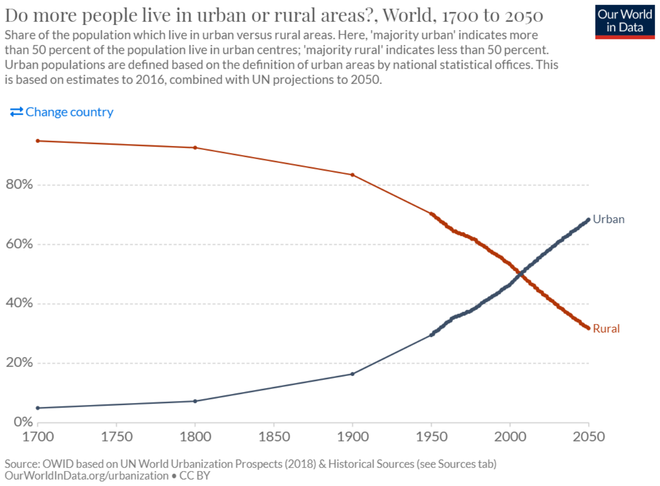


Figure 2.1: *UN projections of urban and rural population.*
[8]

With more and more people moving to urban cities, the need for transportation will increase proportionally. Transportation is dependent on where people live. With increase in transportation demand in cities and urban areas also increases, there will be environmental challenges. A solution to this challenge is implementation of artificial intelligence in vehicles, which can solve numerous challenges.

According to (Weldu, 2018)[9] technological advancement in the auto industry is making autonomous vehicles a reality of the near future. Moreover, 11 largest automakers are planning to have a fully autonomous vehicle on the road between 2018 and 2021 which will be a little bit delayed because of the global pandemic. The autonomous vehicles can disrupt the transportation system in many ways. It could facilitate better mobility allowing people with restricted access to public transport get services that suit their activities. On the contrary, they could initiate a privatized mobility system where they take away people from the public transport.

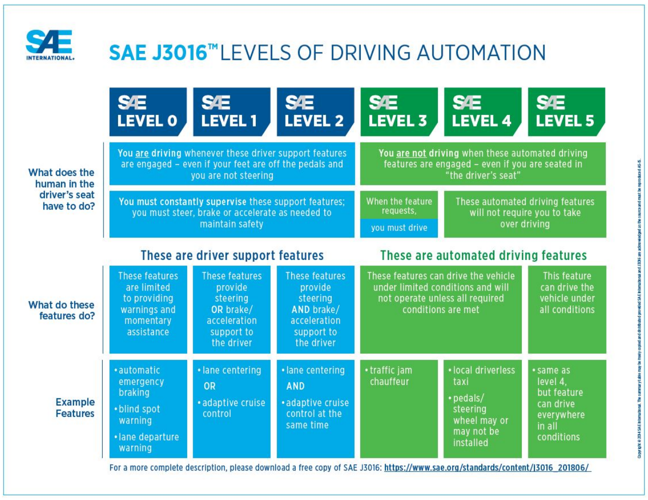
The technological innovation in the auto industry could reduce traffic accidents and manage traffic congestion. These vehicles are using the technological developments to increase traffic safety. The technology is an essential component of the autonomous vehicles. Moreover, Autonomous vehicles further increase the traffic safety by eliminating the human error. Autonomous vehicles are not out in the streets for people to benefit. It is necessary to be familiar with the different automation levels of the auto industry and keep in mind that their impact could also vary from city to city. (Weldu, 2018)[9]

2.2 Autonomous vehicles

The convergence of technology and the city is seen as a possible remedy to overcome the challenges of urbanization such as climate change, congestion, and greenhouse gas (GHG) emissions. Transport, as an integral part of the city, is responsible for about a quarter to one-third of GHG emissions. Technology in the name of smart urban mobility is becoming a key concept of the contemporary urban policy agenda to address the undesirable effects of transport. As originally conceived within the smart cities agenda, the smart urban mobility concept is characterized by an integration of sustainable and smart vehicular technologies, and cooperative intelligent transport systems (ITS) through cloud-servers and big-data-based vehicular networks. In other words, smart urban mobility is conceptualized as urban traffic services combined with smart technologies. Undoubtedly one of the most advanced applications that utilizes numerous ITS tools as a part of the smart urban transport system is autonomous vehicle (AV)—a.k.a. automated car, self-driving car or driverless car. (Asif Faisal et al., 2019)[10]

As stated in (Weldu, 2018)[9] autonomous vehicles (AVs) are vehicles which can operate without the influence of a human driver. AVs use different sensor technologies for the operation of driving such as Supplemental sensors, vision system, Lidar system and Radar system. These functions help on sensing and seeing the surrounding and have a 3D image of the world. However, Self-driving vehicles or AVs vary in their degree of automation. A fully AV is a vehicle which can navigate without the complete intervention of human on the travel from A to B. Automated vehicles have different technological and functional levels defining the degree of their automation.

To set agreed-upon standards early in the transition to autonomous vehicles, the Society of Automotive Engineers (SAE) developed a classification system that defines the degree of driving automation a car and its equipment may offer. Ranging from levels zero to five, the driving automation spectrum begins with vehicles without this technology and ends with entirely self-driving vehicles. If a vehicle has Level 0, Level 1, or Level 2 driver support systems, an active and engaged driver is required. She is always responsible for the vehicle’s operation, must supervise the technology at all times, and must take complete control of the vehicle when necessary. In the future, if a vehicle has Level 3, Level 4, or Level 5 automated driving systems, the technology takes complete control of the driving without human supervision. However, with Level 3, if the vehicle alerts the driver and requests she takes control of the vehicle, she must be prepared and able to do so. Furthermore we are going to go through the different levels in more detail. (Choksey and Wardlaw, 2021)[11] On figure 2.2 you can see a brief description of the different levels and functionalities.



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

For a more complete description, please download a free copy of SAE J3016: https://www.sae.org/standards/content/j3016_201806/

Figure 2.2: *Levels of Driving Automation.*
[12]

According to (Choksey and Wardlaw, 2021)[11] these are the different levels of driving automation.

Level 0 – No Driving Automation
Level 0 (zero) refers to a vehicle that has no driving automation technology. In this case, the driver is entirely in charge of operating the vehicle's movement, including steering, accelerating, braking, parking, and any other necessary maneuver to move the car in any direction.

However, at Level 0, driver support systems that may temporarily intervene during driving may be present. Examples include stability control, forward-collision warning, automatic emergency braking, blind-spot warning, and lane-keeping assistance. These technologies are considered Level 0 because they do not drive the vehicle but offer alerts or momentary action in specific situations.

Level 1 Driving Automation – Driver Assistance
At Level 1, the lowest rung of automation, a vehicle has at least one driver support system that provides steering assistance OR braking and acceleration assistance. The driver remains responsible for driving the vehicle and must be prepared to take control at any time and for any reason.

Adaptive cruise control is an example of a Level 1 driver assistance technology. It maintains a safe following distance between your vehicle and traffic ahead without any intervention by the driver. A steering assistance feature, such as lane-centering assistance or lane-following assistance, would also qualify as Level 1 autonomy.

However, a vehicle with both of these features working together qualifies as Level 2 driving automation.

Level 2 Driving Automation – Partial Driving Automation
Level 2 driving automation applies to vehicles with advanced driving assistance systems (ADAS) that can take over steering, acceleration, and braking in specific scenarios. But, even though Level 2 driver support can control these primary driving tasks, the driver must remain alert and is required to actively supervise the technology at all times.

An example of Level 2 driving automation is Highway Driving Assist, installed in Genesis, Hyundai, and Kia vehicles. It requires the driver to have her hands on the steering wheel but actively steers, accelerates, and brakes the vehicle when traveling on highways. BlueCruise is a new hands-free partial driving automation technology from Ford. It is more sophisticated than Highway Driving Assist, allowing the driver to take her hands off of the steering wheel on specific, approved highways in the U.S. and Canada.

Both of these examples of Level 2 driving automation require the driver to remain alert, engaged, and ready to take control at any time. For the record, and according to what the automaker told the state of California, Tesla's new Full Self Driving Capability technology is a Level 2 system, and it will remain so when Autosteer for city streets arrives as an over-the-air software update.

Level 3 Driving Automation – Conditional Driving Automation
The leap from Level 2 to Level 3 automation is significant, so no Level 3 systems are legal to use on American roads. Yet.

Level 3 is known as conditional driving automation. It uses various driver assistance systems and artificial intelligence to make decisions based on changing driving situations around the vehicle. People inside the vehicle do not need to supervise the technology, which means they can engage in other activities. However, a human driver must be present, alert, and able to take control of the vehicle at any time, especially in the case of an emergency due to system failure.

No, you still cannot take a nap while sitting in the driver's seat.

Audi developed a Level 3 traffic jam assistance technology for its 2019 A8 flagship sedan, but it never received regulatory approval for the system in Germany and has since shelved the effort. That opened the door for Honda to become the first automaker in the world to sell an approved Level 3 traffic jam assistance system to consumers. It went on sale as an upgrade to the company's Legend flagship sedan in early 2021, offered in low quantities and only for use in the automaker's home market of Japan.

Other vehicles equipped with Level 3 driving automation but waiting for regulatory approval include the redesigned 2021 Mercedes-Benz S-Class and the all-new 2022 Mercedes-Benz EQS electric vehicle. The Mercedes technology is called Drive Pilot.

Level 4 Driving Automation – High Driving Automation
Referred to as high-driving automation, Level 4 autonomy does not require any human interaction in the vehicle's operation because it is programmed to stop itself in the event of system failure. Since a human driver is never needed, a Level 4 vehicle may not have a steering wheel and pedals.

And yes, at Level 4, you can take a nap while riding in the vehicle.

Level 4 driving automation technology is for use in driverless taxis and public transportation services. Such vehicles will be programmed to travel between Point A and Point B and restricted to specific geographic boundaries by geofencing technology. Certain conditions may limit or cancel Level 4 autonomous vehicle operation, such as severe weather.

Level 5 Driving Automation – Full Driving Automation
As the highest classification of driving automation, Level 5 means a vehicle can drive itself everywhere in all conditions without any human interaction. A Level 5 vehicle is neither bound by geofencing nor affected by weather and transports human beings comfortably and efficiently without requiring a driver. The only human involvement will be to set a destination.

There are two ways to utilize AVs. One is as privately-owned cars and the second is as shared mobility. The use of AVs as privately-owned cars could create several concerns and potential problems if added to the current car park. Privately owned AVs could initiate long car trips where people had previously used public transport because of frustration, boredom, and fatigue of driving for long hours. They could increase vehicle kilometer travel (VKT) as they could provide access to people who previously relied on the public transport, walking, and cycling due to inability to drive personal vehicles. They could also invite more car travel in city centers where previously was avoided due to travel cost and unavailability of parking. On the other hand, AVs functioning as shared mobility could reduce ownership of private vehicles which could lead to less number of cars. They could drastically improve mobility for people that do not have cars. They could also free more road space and parking areas. Different countries and continents have different approaches to the development of AVs. The European Intelligent Transport Systems (ITS) and the Norwegian ITS departments are working on the utilizing Autonomous vehicles as a Connected Cooperated and Automated Mobility (CCAM) system. (Weldu, 2018)[9]

Chapter 3

Literature Review

The world we are living in today feels, in many ways, like a Wonderland similar to the one that the British mathematician Charles Lutwidge Dodgson, better known under the name Lewis Carroll, described in his famous novels. Image recognition, smart speakers, and self-driving cars—all of this is possible due to advances in artificial intelligence (AI), defined as “a system’s ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation.” Established as an academic discipline in the 1950s, AI remained an area of relative scientific obscurity and limited practical interest for over half a century. Today, due to the rise of Big Data and improvements in computing power, it has entered the business environment and public conversation. AI can be classified into analytical, human-inspired, and humanized AI depending on the types of intelligence it exhibits (cognitive, emotional, and social intelligence) or into Artificial Narrow, General, and Super Intelligence by its evolutionary stage. What all of these types have in common, however, is that when AI reaches mainstream usage it is frequently no longer considered as such. This phenomenon is described as the AI effect, which occurs when onlookers discount the behavior of an AI program by arguing that it is not real intelligence. As the British science fiction writer Arthur Clarke once said, “Any sufficiently advanced technology is indistinguishable from magic.” Yet when one understands the technology, the magic disappears. (Haenlein and Kaplan, 2019)[13]

The literature review aim to briefly present, summarize and review relevant publications regarding the research question. Section 2.1 presents an article related to the limitations of implementing AI in vehicles, Section 2.2 presents articles regarding the benefits that stems from implementing AI. In regards to the challenges, Section 2.3 addresses the associated challenges that AI in vehicles will have, 2.4 the history and 2.5 the future of AI in vehicles. Finally section 2.7 addresses the improvements needed to the current state of autonomous vehicles.

3.1 Limitations of AI

To start the extensive development of autonomous vehicles, there are obstacles and limitations that needs to be overcome. Countries have many regulations that companies have to abide by, some countries have of course less because of the more capitalistic approach to development. There are also numerous countries which do not have the financial capability to invest in the infrastructure that is needed for the research and development of AVs ie. developing countries. And some countries don't have the sufficient manpower that is required, like small populated countries. As stated there are many limitations to the development of Avs. In this section I am going to go deeper into what exactly these limitations are. (Harkut, 2019)[14]

Building trust
The AI is all about science, technology, and algorithms which mostly people are unaware of, which makes it difficult for them to trust it.

AI human interface
Being a new technology, there is a huge shortage of working manpower having data analytics and data science skills; those in turn can be deputed to get maximum output from artificial intelligence. As the advancement of AI rising businesses lack a skilled professional who can match the requirement and work with this technology. Business owners need to train their professionals to be able to leverage the benefits of this technology.

Investment
AI is an expensive technology that not every businesses can invest capital into, a large amount of computing power will be necessary and sometimes hardware acceleration with GPU, FPGA, or ASIC must be in place to run machine learning models effectively. Though adoptability of AI is surging high, it has not been integrated fully in business's value chain at the scale which it should have. Moreover, enterprises of those who have incorporated are still in nascent stage which have resulted in the slowdown in the lifting of the AI technology at scale and thus been deprived of cost benefit of scale. After decades of speculation and justifiable anxiety about the social implications of intensifying potentially de-stabilizing AI technology for humankind and Black box problem, AI investors are bit skeptical from parking their money in potential startups.

Software malfunction
With machines and algorithms controlling AI, decision-making ability is automatically ceded to code-driven Black Box tools. Automation makes it difficult

to identify the cause of mistakes and malfunctions. Moreover, due to the lack of ability of human beings to learn and understand how these tools work, they have little or no control over the system which is further complicated as automated systems become more prevalent and complex.

Non-invincible (Can replace only certain tasks) Like any other technology, AI also has its own limitations; it simply cannot replace all tasks. However, it will result in emerging new job domain with different quality job profile.

High expectations
Research in artificial intelligence is conducted by large pool of technologist and scientists with varying objectives, motivation perspectives, and interests. Main focus of research is confined in understanding the underlying basis of cognition and intelligence with heavy emphasis on unraveling the mysteries of human intelligence and thought process. Not everyone understands the functioning of AI and might also have very high expectation of functioning.

Data security
Machine learning and decision-making capability of AI and AI application are based on huge volumes of classified data, often sensitive and personal in nature. This makes it vulnerable to serious issues like data breach and identity theft. Mostly, companies and government striving for profits and power, respectively, exploit the AI-based tools which are generally globally networked which make them difficult to regulate or rein in.

Algorithm bias
AI is all about data and algorithms. Accuracy of decision-making capability of AI is purely based on how accurately it has been trained and by using authentic and unbiased data. Unethical and unfair consequences are inherent in vital decision-making if data used for training is laced with racial, gender, communal, or ethnic biases. Such biases will probably be more accentuated, as many AI systems will continue to be trained using bad data.

Data scarcity
Power and capabilities of AI and AI applications depend directly on the accuracy and relevancy of supervised and labeled datasets being used for training and learning. There is scarcity of quality-labeled data. Though efforts are underway by means of transfer learning, active learning, deep learning, and unsupervised learning, to devise methodologies to make AI models learn despite the scarcity of quality-labeled data, it will only aggravate the problem.

3.2 Benefits

The development of autonomous vehicles is a disruptive technology for the whole transport sector. Most developments in this field have been concentrated on the private car. The benefits of AVs are multiple, most commonly they are associated with higher safety, lower congestion, fewer crashes, higher fuel efficiency and declining human resource costs.

Social benefits
Industry reports and marketing efforts, frequently cited in popular press, paint a picture of how AVs will revolutionise our lives by freeing up driving time for doing other sorts of productive or fun activities while we travel. Waymo talks about how "Time spent commuting could be spent doing what you want". A report by KPMG and CAR begins by asking readers to "imagine" scenarios where one can work seamlessly from the office to home, catch up on emails, or read many books and watch movies during the commute. The report's authors interviewed dozens of industry leaders and concluded that AVs "offer travelers the opportunity to regain time formerly lost to driving as productive time," declaring that "all or part of this time is recoverable". They even go so far as to suggest that AVs will be customised as "mobile offices, sleep pods, or entertainment centers," without discussing whether laws and regulations will allow this or if the market with support such a diversification of vehicle types. Morgan Stanley estimates that full adoption of AVs could net the US economy over $500 billion per year "from people now being able to work" in the car, assuming (perhaps optimistically) that 30% of all travel time could be spent working at 90% productivity. Globally, AVs could provide travellers up to one billion hours per day of time savings that could be used for working, relaxing, or being entertained, according to estimates by experts interviewed by McKinsey Company.(Singleton, 2019)[15]

Efficiency Benefits
According to (Baker and Beiker, 2014)[16] electric vehicles are inherently well suited for automation thanks to their drive-by-wire controls and electric actuation systems. Likewise, AVs may be more amenable to electrification than combustion vehicles, because a vehicle can be dispatched to meet a user's specific need, only serving trips within range. AVs would also reduce or eliminate plug-in electric vehicle infrastructure challenges since they would be aware of the availability and location of charging options. Lastly, because upfront cost is currently a barrier to PEVs, distributing that cost over many users can increase the relative competitiveness of PEVs as an option for many trips. While the potential more travel/on-demand AV system effects could cause range limitation issues to persist,

it is conceivable that vehicle recharging could be coordinated in between scheduled trips. Having greater driving miles would also increase the importance of operating cost considerations, as well as the potential for lower cost fuels (such as electricity, even with occasional liquid fuel range extension) to pay back an initial vehicle purchase price premium. While vehicle electrification could certainly happen anyway, the above arguments explain why AVs may make broad PEV penetration more likely. The key factor here is estimating the fraction of vehicles that could easily be electrified under an AV scenario. Assumptions are generated from a high-level estimate from an analysis based on NHTS data of the number of trips by length. They assume that vehicles satisfying trips of fewer than 40 miles could be replaced by electric vehicles. This would allow 75% of the fleet to be electric vehicles, resulting in a 75% decrease in fuel intensity. This is only the petroleum FI(liquid fuel/miles traveled); the electricity would need to be produced and the method of production could affect the total energy and carbon intensity of the vehicle fleet.

There is also potential large energy savings from improved vehicle operation of AVs relative to the average human driver. It is well documented that smoother starts and stops can improve fuel economy of otherwise identical vehicles. To estimate the size of this effect, we reference recent eco-driving analyses that identify potential fuel savings for aggressive drivers as high as 20–30 %. The fuel savings for drivers who are not at the most aggressive end of the spectrum would be significantly less, but considering AVs' ability to constantly maintain eco-driving vigilance, we assume an upper bound of 15 % for the potential widespread improvement in EI(energy required/miles traveled). (Baker and Beiker, 2014)[16]

It is also stated in (Baker and Beiker, 2014)[16] that smart routing to the most energy efficient route has the potential to save energy in addition to efficient operation. This could be due to avoidance of traffic, use of a shorter but modestly slower route, or selection of a route with fewer stops. Of the few quantitative efficient routing impact estimates found in their literature review, one case study in the Buffalo, NY area estimated up to 20 % total reduction in EI as possible. However, this estimate really represented a potential system-level impact of re-routing some vehicles in order to improve the operating efficiency for all vehicles on the traffic network. Another recent study of efficient routing for a plug-in electrified vehicle (PEV) identified up to 5 % overall energy savings, taking into account times when the default route already represented the most efficient route, and not taking into account traffic flow impacts from all vehicles simultaneously optimizing system-level routing efficiency. Because system-level traffic smoothing impacts will be separately considered, 5 % was taken as the widespread upper bound EI improvement for this analysis.

Americans use a significant amount of time and energy during city driving searching for parking. AVs could seamlessly integrate into a smart transportation system and either find open parking or drop off the occupants without the need to park. The Texas Transportation Institute reported that the fuel wasted is around 19 gallons a person per year. If we assume that amount could be cut in half by AVs (which would still need to park somewhere, but would not need to search), that would be a 4 % reduction in UI(miles traveled/vehicle).(Baker and Beiker, 2014)[16]

On-demand mobility is the use of shared vehicles accessed on-demand. Travelers typically reserve a vehicle or ride via a smartphone application ("app") shortly before the trip is made. On-demand mobility fits into the broader and burgeoning area of mobility and the sharing economy, which is the shared use of a vehicle, bicycle, or other transportation mode on an as-needed basis. The sharing economy is a developing phenomenon around renting and borrowing goods and services rather than owning them. This sharing can take place among peers (peer-to-peer) or through businesses (business-to-consumer). With further advances in technology and a developing societal paradigm in which access is valued differently than ownership, shared-use mobility services could continue to grow substantially in use and impact in the coming years. (Greenblatt and Shaheen, 2015)[17]
AVs have the potential to increase vehicle occupancy in some cases. In a shareduse model, multiple options could be available to a user, including a cheaper trip that involves sharing the vehicle with other users, similar to the airport shuttle model of transit. How many users would opt for this is highly uncertain. Here we assume AVs allow the higher end of potential impact of "dynamic ridesharing" as reviewed by the Transportation Energy Futures study, which includes accounting for trip characteristics. That is a 12 % reduction in UI.(Baker and Beiker, 2014)[16]

According to Anderson et al. (2014)[18] autonomous vehicles could substantially increase access and mobility across a range of populations currently unable or not permitted to use conventional automobiles. These include the disabled, older citizens, and children under the age of 16(18 in Norway). Some benefits for this group include personal independence, reduction in social isolation, and access to essential services. Where existing public transit agencies provide services to the disabled, 14 to 18 percent of their budgets, on average, are used to provide on-demand paratransit services. The per-trip costs of these services are often three or more times those of fixed-route transit services. Automation could expand mobility and access at reduced costs. While most of this category of

benefits would be provided to users of these AVs, there would also be a broader societal benefit in reducing the amount of paratransit services.
In (Baker and Beiker, 2014)[16] there is examined data from the 2009 National Highway Transportation Survey and the 2003 "Freedom to Travel" study that reveals that travel varies significantly by age, with a peak at age 40 and is lowest during childhood and old age (Fig. 3.1). In principle, if all segments traveled as much as the 40-year-old segment then the miles of travel distribution would rise upward to align with the population distribution shown in Fig. 2.1. That method would yield an increase in miles of 70%, but would seem to overstate extra travel even for this upper bound analysis. We instead estimate that increased travel under this effect could reach up to 40%, which corresponds with each population segment from age 16 to 85 traveling as much as the top decile. Additionally, the 19% of Americans who are disabled individuals leave the home less frequently, are less likely to travel by car, and take fewer long distance trips, resulting in fewer miles per person. If AVs allow disabled individuals to make the same length and number of car trips, their per-capita VMT could increase by more than 50%. Because we do not have the data to address interactions with the age-based approach discussed above, we do not include this as a separate factor and instead take the 40% estimate to include increased travel by disabled individuals. It should be emphasized that providing better transportation services to these populations would yield significant social benefits, which should not be overlooked or ignored when considering energy impacts.

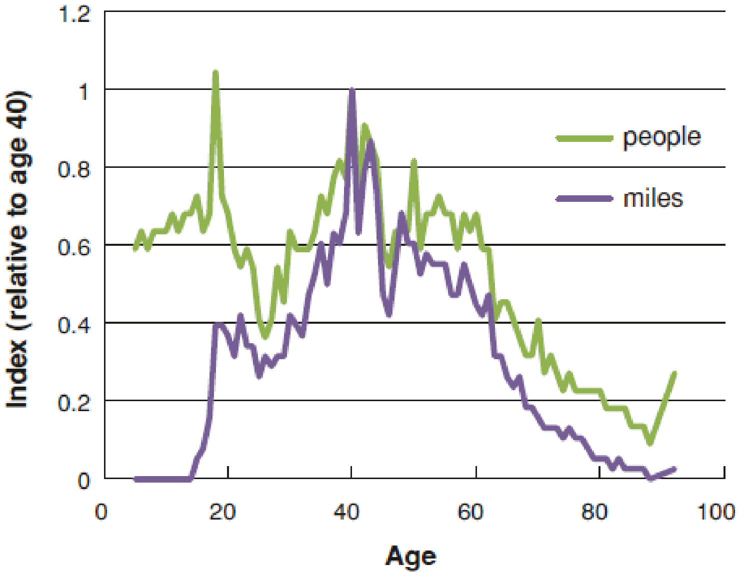


Figure 3.1: *Travel by segment of population in US.*
[16]

Environmental Benefits

While many environmental factors are worth considering including: impacts on air quality, water consumption, land use change, and biodiversity, we limit our environmental impact assessment to greenhouse gas (GHG) emissions. However, it is worth mentioning the potentially large impacts on urban land use through increased road use and decreased parking requirements that AVs may engender. Parking currently adds from 1.3 to 25 grams of carbon dioxide equivalent/passenger-kilometer (km) to total lifecycle GHG emissions of vehicle transport, depending on the scenario, and from 24 to 89% to sulfur dioxide and 10 µm particulate matter emissions; with a large decrease in parking requirements, a substantial fraction of these emissions could be eliminated. Although the impacts on human health would lie primarily in reduced accidents, though if AVs enable greater use of battery electric vehicles or hydrogen fuel cell vehicles, improvements in air quality would also be significant because these technologies emit no ozone-forming precursors (nitrogen oxides, volatile organic compounds) or particulate matter that can cause respiratory illnesses.(Greenplatt and Shaheen, 2015)[17]

Cost savings

According to (Fagnant and Kockelman, 2015)[19] one barrier to large-scale market adoption is the cost of AV platforms. The technology needed for an AV includes the addition of new sensors, communication and guidance technology, and software for each automobile. KPMG and CAR49 note that the Light Detection and Ranging (LIDAR) systems on top of Google's AVs cost $70,000, and additional costs will accrue from other sensors, software, engineering, and added power and computing requirements. Dellenback50 estimates that most current civilian and military AV applications cost over $100,000. This is unaffordable for most people. As with electric vehicles, technological advances and largescale production promise greater affordability over time. Current estimates and analysis states that added costs may fall to between $25,000 and $50,000 (per AV) with mass production, and likely will not fall to $10,000 for at least 10 years. Insurance, fuel, and parking-cost savings may cover much of the added investment. Typical annual ownership and operating costs ranged from $6,000 to $13,000, depending on vehicle model and mileage, with insurance and fuel costs around $900 to $1,000 and $1,100 to $3,700, respectively. These costs may fall by 50 percent for insurance and 13 percent for fuel costs and substantial further savings may be realized in expensive parking environments.

Safety Improvements

The AV industry and authorities claim that improved traffic safety would be one of the significant beneficial impacts of AV use. In 2017, 37,133 people were killed in motor vehicle crashes in the United States (including nearly 7,000 pedestrians and cyclists). Of all serious motor vehicle crashes, 94% involve driver-related factors, such as impaired driving, distraction, and speeding or illegal maneuvers. Globally, road traffic incidents are one of the leading causes of mortality, with 1.3 million people killed each year, and almost 90% of those road traffic deaths are concentrated in low- and middle-income countries, despite that these countries have 48% of the world's registered vehicles. A relevant health consideration on traffic safety is that the majority of traffic injuries and fatalities in the United States happened in individuals between ages 16 and 40 years old, where the number of years lived with disability or years of life lost are greater.

Fully automated vehicles could lead to reductions in the number of driver-related crashes. Luttrell et al. (2015)[20] modeled the expected impacts of AVs on motor vehicle crash injuries and fatalities. They estimated that if 90% of the automobiles in the United States became autonomous, an estimated 25,000 lives could be saved each year, with annual economic savings estimated at more than $200 billion in the United States. These impacts are highly dependent on the market penetration of AVs and are expected to be small initially but to grow as AVs are more widely adopted. The safety benefits of AVs are expected to emerge more rapidly in wealthy countries, which will adopt AVs sooner, than in low- and middle-income countries, where adoption will lag—a paradox given the higher risk in low- and middle-income settings. A barrier to the rapid adoption of AVs is public reluctance due to high-profile news coverage of AV crashes in recent years. Improved road safety related to AV use may also lead to a decline in organ donations. In 2018 in the United States, organ donations from motor vehicle crashes represented 13% of all donations. The implementation of AVs should, therefore, trigger efforts to promote and strengthen organ donation systems.(Rojas-Rueda et al., 2020)[21]

3.3 Challenges

Implementing Artificial Intelligence in vehicles comes also with numerous challenges. Both technical and ethical challenges that needs too be solved before wide spread adoption of autonomous vehicles can be applied.

Safety Challenges

According to (Taeihagh and Lim, 2018)[22] adopting AVs can potentially reduce or eliminate the largest cause of car accidents while also outperforming human drivers in perception, decision-making and execution. However, AVs introduce new safety issues. With autonomous vehicles occupants may reduce seatbelt use and pedestrians may become less cautious due to feeling safer. Also, the elimination of human error does not imply the elimination of machine error. As the technology grows in complexity, so does the probability of technical errors compromising vehicle safety. The fatal crash of Tesla's autopilot in 2016 reveals the uncertainty of machine perception and highlights the technology's inability to avoid accidents in certain scenarios. Concerns also arise regarding how AVs should be programmed by "crash algorithms" to respond during unavoidable accidents. Due to the "lack of blame", the damage caused by AVs in accidents cannot be assessed subjectively, which necessitates rules to regulate AVs' reactions to moral dilemmas. However, it is unclear how to arrive at these rules. Algorithms may be programmed to prioritise the safety of the AVs' occupants "over anything else", which ensures the economic viability of developing AVs, but using the individual self-interest of AV occupants as a basis to justify the harm inflicted on others undermines the functions of law itself. In contrast, algorithms may be programmed to achieve the most socially beneficial decision based on a range of factors, but how to arrive at these factors is still unclear. Also, regulators have yet to agree on an acceptable level of safety or define legitimate methods of determining the safety of AVs. AVs' performance could improve over time with real-world driving experience, but this is only possible if the public accepts the technology.

Connectivity Challenges AVs are reliant on sensors, high definition maps and other instruments, from which information is collected and optimised to ensure the vehicle's safe operation. However, concerns arise regarding who controls this information, and how it is used. Multiple issues regarding informational privacy remain unclear: the exact reasons why information is being collected, the types of information being collected, accessibility to the information and the permissible duration of information storage have not been clarified. V2V and V2I communications allow information to be transmitted between AVs for safety reasons, but they also expose the vehicle's movements and geographical location to external networks, from which people can access to locate an AV user. There are inadequacies of protecting location-based data based on customer consent, customers accept the terms and conditions without fully understanding them. Another issue is the use of EDRs for ascertaining the exact causes of accidents, as this data may be sold to third parties such as insurance companies and used against drivers. Other cited risks to informational privacy are the possibility of using this information to harass AV users through marketing and advertising, to steal users' identity, profile users and predict their actions, concentrating information and power over large numbers of individuals. While it is possible to anonymise the information taken, this can be reversed through deanonymisation.

Deanonymisation algorithms can re-identify anonymised micro-data with high probability, demonstrating that anonymisation is insufficient for data privacy. This is a serious problem for location-based data, as human traces are unique, enabling an adversary to trace movements even with limited side information. Also, access to the interconnected AVs wireless network enables public and private agencies to conduct remote surveillance of AV users, which can undermine individual autonomy through psychological manipulation and intimidation. Another emerging issue is the use of video surveillance in AVs that are used as a transportation service, such as autonomous taxis. As users do not own these AVs, it is unclear whether the vehicle is considered a “public space” where surveillance can be considered acceptable.(Taeihagh and Lim, 2018)[22]

Cyber-attacks

As stated in (Taeihagh and Lim, 2018)[22] cybersecurity threats to conventional vehicles with automated features already exist. In a survey of 5000 respondents across 109 countries, people were most concerned about software hacking and misuse of vehicles with all levels of automation. Hackers could take control of the vehicle through wireless networks (such as Bluetooth, keyless entry systems, cellular or other connections) as the car connects with the environment. With its ability to store and transmit transaction and lifestyle data, AVs are attractive targets for hackers as such information can be sold for a financial gain, or these systems can be used to inflict physical harm by extremists or used for illegal purposes by drug traffickers. For instance, it was demonstrated in this article that malicious attacks on AVs are a near-term possibility in 2013, as they hacked a ChryslerJeep through its internet connection and took control of its engines and brakes. Various studies have analysed the possible cybersecurity threats to AVs, as computers possess greater control over the movements of an AV, AVs are more vulnerable to hacking than conventional vehicles, and the driver is less able to intervene during an attack. Without sufficient security, V2V and V2I communication channels can be hacked, which can lead to serious accidents. Injection of fake messages and spoofing of global navigation satellite systems (GNSS) are some of the major threats that AVs will face, as GNSS data can be manipulated to undermine the AVs’ safety critical functions. Other threats include the use of sensor manipulation to disorient the AV’s systems, bright lights to blind cameras and ultrasound or radar interference to blind an AV from incoming obstacles. While systems may be installed to detect such malfunctions, these require software updates as well as changing existing standardised security architectures. Most governments have developed non-mandatory guidelines on cybersecurity best practices and researched to explore the implications of AVs on cybersecurity. Governments in the US, China, EU, and Singapore have adopted a control-oriented strategy and have introduced or enacted new legislations to address cybersecurity risks.

Labor Challenges Literature suggests that technological advancements pose a threat to many existing lowskilled, manual jobs, as these are easily automated. Drivers and mechanics are especially at risk as their value-added is derived from the driving task and they tend to be older and less educated. If the regulatory environment favours widespread adoption, AVs will have immense employment implications. Simulation studies suggest that taxi fleets could be reduced in size to 10% in Berlin, and to one third in Singapore if autonomous taxi services also replaced traditional public transport. In Singapore, where start-up nuTonomy launched driverless taxis for the first time in the world, nearly half of the privately-owned cars may be redundant in future. Truck drivers and bus drivers are also at risk due to the massive cost savings from eliminating labour. It is estimated that the trucking and delivery industries will gain \$100–\$500 billion from AVs by 2025, most of which will come from eliminating drivers' wages; while shifting truck drivers to more technical roles, such as monitoring AV systems, will barely make up for the millions of jobs lost. Overall, the net economic effects of introducing AVs are estimated to be positive, but the redistribution of employment will negatively impact lower-skilled workers the most, as these displaced workers may spillover to other low-skilled occupations, creating downward pressure on their wages, which can exacerbate inequality. (Taeihagh and Lim, 2018)[22]

Policy Challenges
The introduction and potential proliferation of autonomous vehicles present the classic challenge of balancing the freedom of private manufacturers to innovate with government's responsibility to protect public health. Autonomous vehicles raise many public health issues beyond their potential to improve safety, ranging from concerns about more automobile use and less use of healthier alternatives like biking or walking to concerns that focusing on autonomous vehicles may distract attention and divert funding from efforts to improve mass transit. There are, additionally, issues of access, especially for the poor, disabled, and those in rural environments.
There are important and complex policy and regulatory concerns; insurance issues, including the possibility of a no-fault auto insurance system for autonomous vehicles; product and tort liability issues; and issues pertaining to privacy and cybersecurity for all communications into and within the vehicle, all of which are beyond the scope of this article. Finally, we have just begun to explore the effect autonomous vehicles will have on traffic, pollution, and the built environment. Clearly, many issues affect the health of the public beyond accident prevention and, with their considerable skills as researchers, data

analysts, policy advocates, and community catalysts, public health leaders have much to contribute to conversations about health impacts, equity, social justice, and the values of public health.(Fleetwood, 2017)[23]

Ethical Challenges

Finally, ethical issues involving the decisions made by AVs in the case of traffic incidents are a relevant factor to consider. An imminent crash may pose instantaneous decisions about who will die: a passenger or pedestrian, an older person or a child? The moral elements of such decisions must be programmed into the algorithms used by AVs. A recent multinational survey on moral decisions related to AV and road safety found that these moral decisions vary considerably by gender, social status, and nation and appear to reflect underlying societal-level preferences for egalitarianism (47).(Rojas-Rueda et al., 2020)[21]

Fleetwood (2017)[23] provide an example and brief analysis of this ethical issue for autonomous vehicles; the algorithms being created for autonomous vehicles in situations of forced choice, such as whether to hit a parked car or a pedestrian on an ice-covered road. He argues for greater involvement starting now, during the design phase, of public health leaders and describe how the values of public health can guide conversations and ultimate decisions. By reflecting on the ethical and social implications of autonomous vehicles and working collaboratively with designers, manufacturers, companies like Uber and nuTonomy, city health departments, the public, and policymakers on the local, state, and federal level, public health leaders can help develop guidelines that foster equity and safety across the population.(Fleetwood, 2017)[23]

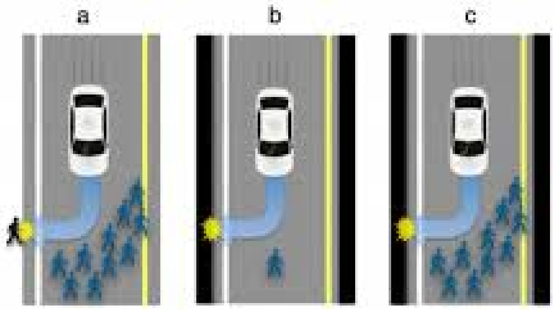
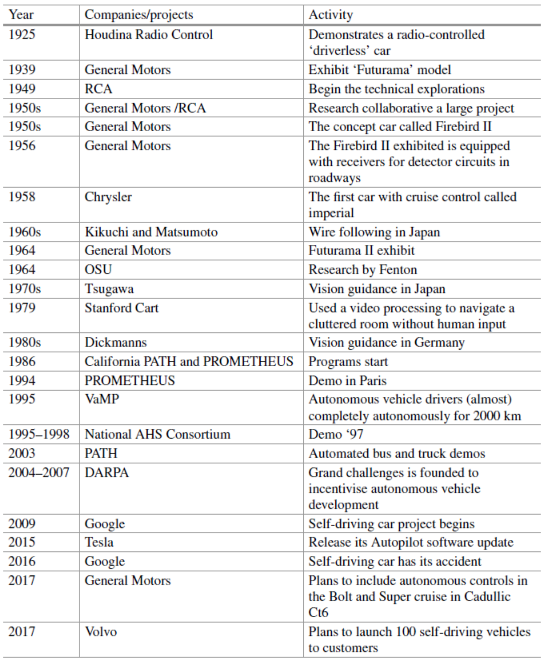


Figure 1: Three traffic situations involving imminent unavoidable harm. (a) The car can stay on course and kill several pedestrians, or swerve and kill one passer-by. (b) The car can stay on course and kill one pedestrian, or swerve and kill its passenger. (c) The car can stay on course and kill several pedestrians, or swerve and kill its passenger.

Figure 3.2: *Travel by segment of population in US.*
[24]

3.4 History of autonomous vehicles

The idea of Autonomous Vehicles started from 1920s when science-fiction writers visualized and innovated the self-driving cars as a new challenge for automotive industries. A brief history of autonomous driving is listed in figure 3.3.(Khayyam et al., 2020) [25]



Year	Companies/projects	Activity
1925	Houdina Radio Control	Demonstrates a radio-controlled ‘driverless’ car
1939	General Motors	Exhibit ‘Futurama’ model
1949	RCA	Begin the technical explorations
1950s	General Motors /RCA	Research collaborative a large project
1950s	General Motors	The concept car called Firebird II
1956	General Motors	The Firebird II exhibited is equipped with receivers for detector circuits in roadways
1958	Chrysler	The first car with cruise control called imperial
1960s	Kikuchi and Matsumoto	Wire following in Japan
1964	General Motors	Futurama II exhibit
1964	OSU	Research by Fenton
1970s	Tsugawa	Vision guidance in Japan
1979	Stanford Cart	Used a video processing to navigate a cluttered room without human input
1980s	Dickmanns	Vision guidance in Germany
1986	California PATH and PROMETHEUS	Programs start
1994	PROMETHEUS	Demo in Paris
1995	VaMP	Autonomous vehicle drivers (almost) completely autonomously for 2000 km
1995–1998	National AHS Consortium	Demo ‘97
2003	PATH	Automated bus and truck demos
2004–2007	DARPA	Grand challenges is founded to incentivise autonomous vehicle development
2009	Google	Self-driving car project begins
2015	Tesla	Release its Autopilot software update
2016	Google	Self-driving car has its accident
2017	General Motors	Plans to include autonomous controls in the Bolt and Super cruise in Cadullic Ct6
2017	Volvo	Plans to launch 100 self-driving vehicles to customers

Figure 3.3: *A brief history of autonomous driving by various research and development projects.*

[25]

The first driverless cars were prototyped as early as the 1920s, although these were not the self-contained autonomous vehicles we see today. Although they nominally lacked a "driver", these vehicles relied heavily on specialized external inputs.

1920s

According to (EngelKing, 2017)[26] the Houdina Radio Control Co., a radio equipment firm, was founded by former U.S. Army electrical engineer Francis P. Houdina. From the get-go, he had his sights set on transportation, and he built what's believed to be the first radio-operated automobile. He rigged a 1926 Chandler sedan with a transmitting antenna, and the radio signals it received operated small electric motors that controlled the vehicle's speed and direction. A crew trailing closely behind in a second vehicle controlled the phantom Chandler.

In the summer of 1925, Houdina's driverless car, called the American Wonder, traveled along Broadway in New York City—trailed by an operator in another vehicle—and down Fifth Avenue through heavy traffic. It turned corners, sped up, slowed down and honked its horn. Unfortunately, the demonstration ended when the American Wonder crashed into another vehicle filled with photographers documenting the event.(EngelKing, 2017)[26]

1930s
The auto industry continued to daydream about remote-controlled cars. At the 1939 World's Fair, the Futurama exhibit by General Motors which featured an enormous motorized diorama of an American city. Free-flowing highways plied by self-driving cars, trucks, and buses crisscrossed bustling districts of slender skyscrapers. There was even a "traffic control tower" where, the future city's designers imagined, dispatchers would direct the movements of tens of thousands of vehicles by radio.(Townsend,2020)[27]

1950s
RCA Labs presented a significantly advanced model for autonomous cars. RCA Labs built a miniature car in 1953. It was controlled and guided by wires that were laid in a pattern on a laboratory floor. Leland Hancock, a traffic engineer in Nebraska, and L. N. Ress, a state engineer took the idea of RCA Labs to a greater scale, by experimenting with the system in actual highway installations, which was done on a 121.92 meters long strip of highway just outside the town of Lincoln, Nebraska, in 1958. A series of detector circuits buried in the pavement were a series of lights along the edge of the road, which were able to send impulses to guide the car and determine the presence and velocity of any metallic vehicle on its surface. General Motors collaborated with it, and paired two standard models with equipment having special radio receivers and audible and visual warning devices that were able to simulate automatic steering, accelerating and brake control. (Bimbraw, 2015)[28] Also in the 1950s, self-contained autonomous systems began to exist in the form of function-specific automation. Cruise control was introduced in the 1958 Imperial, allowing vehicles to maintain speed without driver input.(Jenn, 2016) [26]

1960s
Based on advanced models, in 1959, and throughout the 1960s, in Motorama the auto show, Firebird was showcased by General Motors according to (Bimbraw, 2015)[28], which was a series of experimental cars which had an electronic guide system which could rush it over an automatic highway without driver's involvement. This led to Ohio State University's Communication and Control Systems Laboratory to launch a project to develop driverless cars which were

activated by electronic devices imbedded in the roadway, in 1966. United Kingdom's Transport and Road Research Laboratory tested a driverless car, Citroen DS that interacted with magnetic cables that were embedded in the road, during the 1960s. It went through a test track at 130 km/h without deviation of speed or direction in any weather condition. It travelled in a far more effective way than by human control. The Sure-Brake System was able to monitor wheel speed, analyze this data to detect skidding, and relay commands to a hydraulic modulator, in the same automation model which would be used in countless applications, including autonomous driving.

1970s

Also being developed during the 60s and 70s was the Stanford Cart. Initially a moon rover project, the Stanford Cart team pioneered the video processing technology which would later be used to provide input to autonomous vehicles. Equipped with a swiveling television camera, the rover would process images for ten to fifteen minutes each time it moved one metre. This enabled it to navigate slowly around obstacles without any human input. In 1979, the Stanford Cart autonomously crossed a room crowded with chairs in about five hours. These separate avenues - driverless cars requiring special inputs, function-specific autonomous systems and video processing algorithms for unmanned navigation - soon began to converge. In 1971, Anti-Lock Braking Systems (ABS) were first implemented in automobiles, again in the Imperial, after being used in aircraft since 1929. (Jenn, 2016) [26]

1980s

The late 1970s to 1980s saw the first autonomous cars of the type we know today: self-contained vehicles equipped with the necessary sensors, processors, and outputs to theoretically drive themselves through typical traffic without special external inputs. Ernst Dickmanns, a pioneer of autonomous cars and a professor at Bundeswehr University, led a team in outfitting a Mercedes-Benz van to become just this. The van was able to process visual input from cameras and provide commands to the steering wheel, throttle, and brakes, driving at speeds up to 96 km/h. This was achieved using innovative " 4D Vision " techniques, which involved extracting edges from an image and analyzing them while taking into account the time delay. Again, government organizations invested in this new technology, which held the potential for safer and more lawful roadways. The EUREKA PROMETHEUS project, in which Dickmanns was a participant, was the largest of these initiatives. In 1995, the project culminated in a nearly 2000-km drive at up to 130 km/h, almost completely autonomously, by Dickmanns's VaMP autonomous vehicle.(Jenn, 2016) [26]

1990s

DARPA, Defense Advanced Research Projects Agency of the U.S. Department of Defense is also responsible for the progress in the field of autonomous cars. Autonomous Land Vehicle (ALV) project in the United States made use of new technologies. These technologies were developed by the Carnegie Mellon University, the Environmental Research Institute of Michigan, University of Maryland, Martin Marietta and SRI International. The ALV project achieved the first road- following demonstration that used computer vision, LIDAR and autonomous control to direct a robotic vehicle at speeds of up to 31 km/h. HRL Laboratories (formerly Hughes Research Labs) demonstrated the first off-road map and sensor- based autonomous navigation on the ALV. The vehicle traveled over 610 m at 3.1 km/h on complex terrain with steep slopes, ravines, large rocks, vegetation and other natural obstacles . The newer autonomous vehicles became more and more efficient with time. The twin robot vehicles VaMP and Vita-2 of Daimler- Benz and Ernst Dickmanns of Bundeswehr University Munich, in 1991 drove more than 1,000 km on a Paris three-lane highway in standard heavy traffic at speeds up to 130 km/h, but semi- autonomously with human interventions. They demonstrated autonomous driving in free lanes, convoy driving, and lane changes with autonomous passing of other cars. Highly autonomous vehicles, in some cases exhibited better speeds than human drivers. In 1995, Dickmanns' autonomous S-Class Mercedes-Benz undertook a 1,590 km journey from Munich, in Germany to Copenhagen, in Denmark and back, using jolting computer vision and microprocessors with integral memory designed for parallel processing to react in real time. The robot achieved speeds exceeding 175 km/h on the German Autobahn, with a mean time between human interventions of 9.0 km, or 95% autonomous driving. It drove in traffic, executing various maneuvers to pass other cars. In 1995 itself, the Carnegie Mellon University's Navlab project achieved 98.2% autonomous driving on a 5,000 km cross-country journey which was dubbed "No Hands Across America" or NHOA. The car was semi-autonomous by nature: it used neural networks to control the steering wheel, but throttle and brakes were human-controlled. An advanced autonomous vehicle was exhibited by Alberto Broggi of the University of Parma. He launched the ARGO Project, which worked on making a modified Lancia Thema to follow painted lane marks on a normal highway, in 1996. The apotheosis of the project was a journey of 1,900 km over six days on the roads of northern Italy, with an average speed of 90 km/h. The car operated in fully automatic mode for 94% of its journey, with the longest automatic stretch being 55 km. The vehicle had two low-cost video cameras on board and used stereoscopic vision algorithms to understand its environment. Some countries started using autonomous public transport systems by the dawn of the new millennium.(Bimbraw, 2015)[28]

2000s
In the early 2000s, the ParkShuttle, an autonomous public road transport system, became operational in the Netherlands. US government also started working on autonomous vehicles, mostly for military usage. Demo I (US Army), Demo II (DARPA), and Demo III (US Army), were funded by the US Government. The ability of unmanned ground vehicles to navigate miles of difficult off-road terrain, avoiding obstacles such as rocks and trees was demonstrated by Demo III. Real-Time Control System, which is a hierarchical control system was provided by the National Institute for Standards and Technology. Along with individual vehicles' control (e.g. throttle, steering, and brake), groups of vehicles had their movements automatically coordinated in response to high level goals.(Bimbraw, 2015)[28]

Founded in 2004, the DARPA Grand Challenge incentivised autonomous car development by offering $1 million to the team whose robotic vehicle could successfully navigate an obstacle course. No competitor was successful in completing the inaugural challenge; however, in 2005 five vehicles completed the race for a first prize of $2 million. The first place winner of these successful competitors was Stanley, a vehicle designed by Stanford University and Volkswagen, using technology adapted from the Stanford Cart.

In 2007, the course was changed to an urban setting, requiring competitors to integrate with traffic. Six teams completed this challenge, headed by Carnegie Mellon's Tartan Racing with Stanford and Virginia Tech's entrants following close behind. Other competitors, however, were involved in accidents - the MIT and Braunschweig entrants collided, and another competitor set itself on a course to collide with a pillar. This event gave rise to the predictive and decision-making software required for autonomous vehicles to operate amongst other traffic - as well as public awareness of the mistakes this software can make.(Jenn, 2016)[26]

3.5 Future of autonomous vehicles

As stated in (Elezaj, 2018)[29] most people would agree that driverless cars are the future. With the recent leaps and bounds made in the self-driving car industry, very few people would be bold enough to dispute the fact that these cars will reduce the number of road accident fatalities. Research has shown that the number of U.S. deaths resulting from road accidents could be reduced by more than 90% by the year 2050 because of self-driving cars. But there are also some obstacles with the AV technology that is coming and to know where we're headed, we needed to know where we are now, what autonomous technology exists and what plans companies like Google, Tesla, and others have in store.

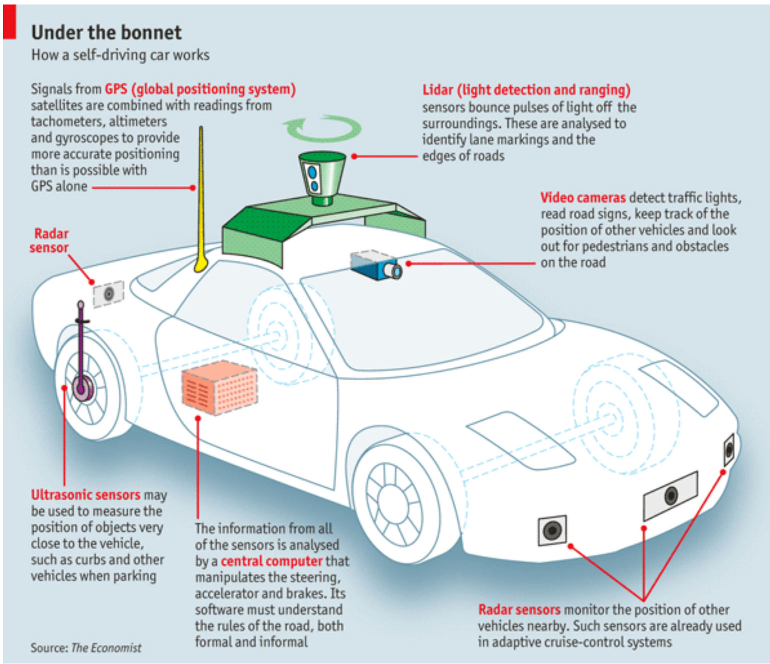
In the past 60 years or so, there have been a handful of tests around the world, but it's really been the last 5-10 years that have seen the most progress in the development and most importantly the testing of these new AI technologies. Not only have there been testing of vehicle that can drive without a human in control, but there have also been developed more autonomous elements and technologies that has become a part of our everyday driving lives. Automatic parking, for example, has become standard on many high-end models including BMW and Mercedes.

Currently, a number of high-profile companies are conducting on-road tests. Waymo, a company owned by Google has already racked up over 5 million miles of testing on public roads in 24 US cities. BMW, who hope to have a fully self-driving car in production by 2021, plans to double their testing fleet to around 80 autonomous vehicles and have pledged to carry out 155 million test miles, 12 million on real roads and the rest in a virtual environment which simulates millions of traffic scenarios. Other manufacturers such as Tesla, Toyota, and the Renault-Nissan Alliance are at similar stages with production vehicles for most of them expected in 2021. While these levels of testing sound impressive, a 2016 study by RAND Corp. reported that to truly demonstrate the reliability of these sort of vehicles, and to show how they handle as many situations as possible, these companies would need hundreds of millions, if not hundreds of billions of test miles.(Elezaj, 2018)

AI is used for several important tasks in a self driving automobile. One of the main tasks is path planning. That is the navigation system of the vehicle. Another big task for AI is the interaction with the sensory system and the interpretation of the data coming out of sensors. The number of sensors with real time data and the need for intelligent processing of the data can be overwhelming. AI is used in the central unit as well as in the multiple electronic control units (ECU) of the modern automobile.

As AI develops and becomes better we will get closer and closer to having secure and autonomous transportation. Until then we have to cope with many hours of development and testing and adoption will be determined by how confident consumers are and will depend on market forces. It is all going to happen even if it takes longer than was originally anticipated. The demand and the need are there and the technology is almost there. Adoption may be faster or slower based on regulation and doing it in phases, starting from simpler and more deterministic use cases such as driving in a known environment. The algorithms used can be sufficiently relieved if the vehicle operates in only specific conditions that present fewer unknowns.

Artificial Intelligence is the most important and sophisticated component of self driving vehicles. A typical autonomous vehicle is shown on figure 3.4.



Under the bonnet

How a self-driving car works

Signals from **GPS (global positioning system)** satellites are combined with readings from tachometers, altimeters and gyroscopes to provide more accurate positioning than is possible with GPS alone

Lidar (light detection and ranging) sensors bounce pulses of light off the surroundings. These are analysed to identify lane markings and the edges of roads

Video cameras detect traffic lights, read road signs, keep track of the position of other vehicles and look out for pedestrians and obstacles on the road

Radar sensor

Ultrasonic sensors may be used to measure the position of objects very close to the vehicle, such as curbs and other vehicles when parking

The information from all of the sensors is analysed by a **central computer** that manipulates the steering, accelerator and brakes. Its software must understand the rules of the road, both formal and informal

Radar sensors monitor the position of other vehicles nearby. Such sensors are already used in adaptive cruise-control systems

Source: *The Economist*

Figure 3.4: *Autonomous Vehicle.*
[30]

There have been extensive research from companies and researchers of what AI application is needed to have safe and viable vehicles on the road, they have frequently come to the same conclusion.
As stated in (Hristov, 2020)[1] the different AI applications and algorithms that are going to be a big part in the future of autonomous vehicles are explained below.

Sensor Data Processing
One of the main tasks is to detect and identify objects ahead and around the vehicle. Artificial neural networks are the algorithms typically used for this task. Another term for this field is deep learning, because a neural network contains many layers that contain many nodes. A deep neural network is shown on figure 3.5 although the number of nodes and layers in practice can be much higher.

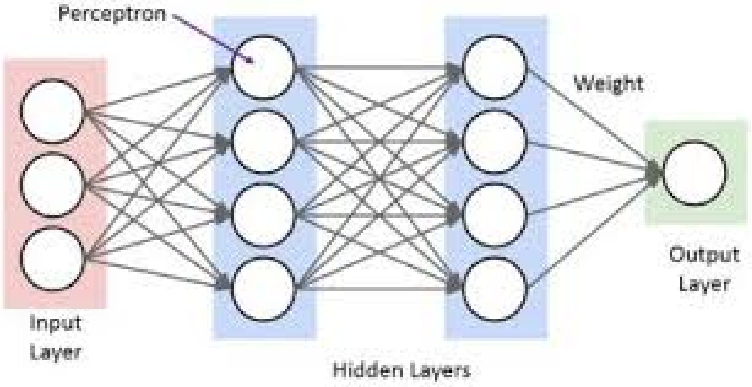


Figure 3.5: *Neural Network Diagram.*
[31]

The analysis of video input uses machine learning algorithms and most likely neural networks in order to classify objects. Since we have multiple sensors of different kind it makes sense to have dedicated hardware/software modules for each sensor. This approach allows for parallel processing of data and therefore faster decision making. Each sensor unit can utilize a different AI algorithm and then communicate its results to the other units or the central processing computer.

Path Planning

Path planning is important in order to optimize the trajectory of the vehicle and to lead to better traffic patterns. This can help reduce delays and avoid congestion on the road. Planning is a very suitable task for artificial intelligence algorithms. It is a dynamic task that can take into consideration a lot of factors and can solve an optimization problem while executing the path. The following definition of path planning is given: ”path planning for AVs enables self-driving vehicles to find the safest, most convenient, and most economically beneficial routes from point A to point B by using the previous driving experiences which help the AI agent make much more accurate decisions in the future”.

Path Execution

After the path is planned the vehicle is able to navigate the road conditions, by detecting objects, pedestrians, bicycles and traffic lights in order to reach the destination. The object detection algorithms are a primary focus of the AI community as they make it possible for human like behavior. The challenges come when different road and weather conditions come into play. Many accidents with testing vehicles happened because the simulation environment is different from the real world conditions and the AI software may react unpredictably when given unknown data.

Monitoring Vehicle's Condition
The most promising type of maintenance is predictive maintenance. It can be defined in the following way: "Predictive maintenance employs monitoring and prediction modelling to determine the condition of the machine and to predict what is likely to fail and when it is going to happen". It tries to predict future problems, not problems that already exist. In this respect predictive maintenance can save a lot of time and money. Both supervised and unsupervised learning can be used for predictive maintenance. The algorithms can use on-board and off-board data to make decision for predictive maintenance. The machine learning algorithms used for this task are classification algorithms like logistic regression, support vector machines and random forest algorithm.

Insurance Data Collection
Data logs from a vehicle can contain information about the driver's behavior and this can be used in the analysis of traffic accidents. These data can be used for processing of claims. All this can contribute to decrease in prices for insurance, since the safety is more deterministic and guaranteed. For fully automated cars the liability will shift from the passenger, who is no longer a driver, to the manufacturer. In the semi-autonomous vehicle, we will still most likely have some liability of the driver. Proving these type of cases will rely more and more on smart data captured by the AI system of the vehicle. Data from all sensors generates enormous amounts of information. Saving all the data at every moment may not be practical, but saving snapshots of relevant data seems the right balance of obtaining evidence that could be used for post analysis of a certain traffic event. This approach is similar to how black box information is stored and analyzed after a crash.

Route Planning and Control Algorithms
Traditional algorithms from computer science that are heuristic in nature can be used for this task. These are algorithms like Bellman-Ford and Dijkstra's algorithm. For these algorithms to work we need to have localization of the vehicle during the whole time. Localization is accomplished through sensors such as GPS as well as simultaneous localization and mapping (SLAM) techniques.
SLAM is used when there is no GPS availability such as underground or enclosed spaces for example. SLAM generates a map of the environment and at the same time estimates the state of a vehicle. The map is composed of landmarks or obstacles in order to represent the environment. SLAM is used in applications where the map is not available and needs to be created. It uses sensors and special algorithms that create models of the data in order to produce the map.

Object Detection Algorithms

Object detection is one of the most important tasks that AI has to handle in a moving vehicle. These algorithms are an area of active research and they rely on different sensors. Object detection can be based on cameras or lidars, radars and other type of sensors. The algorithms used are normally deep learning algorithms which use some type of a neural network to do the job (Redmon et al., 2016).
One requirement for this task is that it needs to be fast. The reason is because there is a succession of images that need to be processed as the vehicle moves. Some of the latest techniques here are based on the use of convolutional neural networks (CNN). These are R-CNN, Fast R-CNN and You Only Look Once (Yolo) methods. RCNN first finds regions that contain potential objects in an image and then tries to analyze each region. This makes R-CNN somewhat slow and that is why there have been fast R-CNN methods developed and the Yolo method. Yolo works simultaneously to find the regions and to classify the objects in the regions by using a single convolutional neural network.This makes Yolo very fast compared to the other methods. In addition Yolo is able to see the entire image and does not suffer from the issues in R-CNN like mistaking background images for objects.

Decision Making Algorithms

Decision making determines the actions of the vehicle based on information from sensors. A vehicle constantly makes decision, based on its policy and the environment. The algorithms used for decision making are the following:

- Decision Trees
- Support Vector Machine (SVM) Regression
- Deep Reinforcement Learning

As the technology and software improves, more and more testing will need to be carried out as they look to refine the process and be able to produce a vehicle that’s able to perform in an almost unlimited set of circumstances. Ford, Hyundai, Kia, Toyota and most other manufacturers plan to have Level 5, fully autonomous cars by 2021 and be producing these vehicles soon after. While the idea of an autonomous vehicle going into production sounds impressive, these are more likely to be small fleets that can only be used in limited situations.
Given the massive expense that comes with testing and developing these vehicles, the cost of the first generation is reported to between $300,000 and $400,000, a price tag that means that most people and most businesses will be priced out of the market. The price will obviously come down as technology evolves and it becomes quicker and easier to manufacture self-driving vehicles, but the

likelihood is that the first experience we'll have of autonomous vehicles will be by using ride-sharing companies like Uber and Lyft.
Unfortunately, it does appear that the first casualties of the growth of driverless cars will be in the delivery and taxiing industry. Lift-share companies will see the opportunity to remove the need for a driver as an attractive prospect and delivery services like Domino's have already begun testing human-less delivery services. Beyond that, truck drivers and other long-distance drivers could see the human element of their industry phased out but this is decades away. Mobility matters and is a fundamental need of every human being. We are constantly on the move to meet our friends and family, travel on holiday or simply go to the store. Car companies have recognized these desires. For example, Volkswagen has developed a shuttle-on – demand (MOIA) which was proven to be highly efficient and flexible. This electric vehicle can be booked by a customer via smartphone app by simply entering their location and destination and the MOIA vehicle comes at a virtual stop up until 250 meters away from the customer and the app navigates the customer to the vehicle. This concept of mobility promotes sharing a journey with other people who are traveling in the same direction and thus preventing traffic congestion, saving the environment by having fewer cars on the roads and reducing traffic. This way of transportation is known as carsharing.(Fig. 3.6) Carsharing existed long before autonomous cars started to emerge, but the difference is that the user no longer must come to the vehicle, but the vehicle comes to the user. Any person who has a valid driver's license can register to the application and use this service upon payment of the registration fee.(Pisarov and Mester, 2020)[32]

Figure 3.6: *Car sharing concept.*
[33]

IoT and digitalization are also a trends that are going to have a major role in the future. There are numerous devices that can be connected together and to the autonomous vehicle.
One cannot argue that new technologies are based and managed through software, digital platforms, and applications. The same thing is applied to new mobility concepts such as carsharing. Mobile applications are inevitable if a person desires to access carsharing vehicles. These apps give the user an insight of the available vehicles and their locations. Next, users decide whether they are willing to go to the vehicle for which they are given no more than 30 minutes. Then, the app books a vehicle and shows the route to it.(Pisarov and Mester, 2020)[32]

3.6 Improvements

Autonomous vehicles are key components in the development of flexible and efficient transport systems for logistics and industrial site management applications. Commercial solutions consisting of fleets of AVs have been developed, e.g., for mining, automated material handling, forklift automation, and industrial vehicle automation. Although these systems are viable commercial products, they can still be improved substantially in terms of efficiency and autonomy, and many key parts of the real-world deployment phase are currently ad hoc and manual.(Andreasson et al., 2015)[34]

To be able to achieve wide spread autonomous driving vehicles, there are many problems that needs to be solved. We need improvements to the current partial automation driving systems that are currently available. One of the most crucial improvements that the largest countries and companies are investing heavily on is sensors and hardware. These are technologies that can detect pedestrians, buildings, animals etc. and will ensure safer vehicles to prevent accidents and fatalities. A deeper insight into different sensors are shown below.

According to (Yurtsever et al., 2020)[35] Exteroceptive sensors are mainly used for perceiving the environment, which includes dynamic and static objects. Camera, lidar, radar and ultrasonic sensors are the most commonly used modalities for this task.

For 360° 2D vision, omnidirectional cameras are used as an alternative to camera arrays. They have seen widespread use, with increasingly compact and high performance hardware being constantly released. Panoramic view is particularly desirable for applications such as navigation, localization and mapping.

Radar, lidar and ultrasonic sensors are very useful in covering the shortcomings of cameras. Depth information, i.e. distance to objects, can be measured effectively to retrieve 3D information with these sensors, and they are not affected by illumination conditions. However, they are active sensors. Radars emit radio waves that bounce back from objects and measure the time of each bounce. Emissions from active sensors can interfere with other systems. Radar is a well-established technology that is both lightweight and cost-effective. For example, radars can fit inside side-mirrors. Radars are cheaper and can detect objects at longer distances than lidars, but the latter are more accurate.

Lidar operates with a similar principle that of radar but it emits infrared light waves instead of radio waves. It has much higher accuracy than radar under 200 meters. Weather conditions such as fog or snow have a negative impact on the performance of lidar. Another aspect is the sensor size: smaller sensors are preferred on the vehicle because of limited space and aerodynamic restraints and lidars are generally larger than radars.

In (Schoettle, 2017)[36], human sensing performance is compared to ADS. One of the key findings of this study is that even though human drivers are still better at reasoning in general, the perception capability of ADSs with sensor-fusion can exceed humans, especially in degraded conditions such as insufficient illumination.

Proprioceptive sensing is another crucial category. Vehicle states such as speed, acceleration and yaw must be continuously measured in order to operate the platform safely with feedback. Almost all of the modern production cars are equipped with proprioceptive sensors. Wheel encoders are mainly used for odometry, Inertial Measurement Units (IMU) are employed for monitoring the velocity and position changes, tachometers are utilized for measuring speed and altimeters for altitude. These signals can be accessed through the CAN(Controller area network) protocol of modern cars. Besides sensors, an ADS needs actuators to manipulate the vehicle and advanced computational units for processing and storing sensor data.

Chapter 4

Case study

4.1 Introduction

In recent years, and especially since the early 1990s, the increase in road traffic and demand for transport have caused serious congestion, delays, accidents and environmental problems, above all in large cities. Traffic congestion has become a veritable scourge which plagues industrialized countries and developing nations alike. It affects both motorists and users of public transport, and as well as reducing economic efficiency it also has other negative effects on society. The disturbing thing is that this expression of modern times has been intensifying, without any sign of having a limit, thus becoming a nightmare that threatens the quality of urban life.

The most obvious consequence of congestion is the increase in travel time, especially at peak periods, which has reached levels well above those considered acceptable in some cities. In addition, the slow pace of circulation is a source of exasperation and triggers aggressive behaviour in drivers. Another result is the exacerbation of environmental pollution. Its relationship with congestion is an aspect that still needs to be studied in greater depth, although valuable evidence has already been obtained in some Latin American cities. Pollution affects the health of all citizens, so that it must be kept below certain limits. Quite apart from the harm caused by pollution at the local level, however, vehicles also emit greenhouse gases, which adds a global dimension to the issue that cannot be overlooked. In addition to the above considerations, there are other important harmful effects which should be taken into account, such as the larger number of accidents, the increase in the consumption of fuel for the distance covered and, in general, the higher operating costs of vehicles. The situation is compounded by the fact that congestion affects not only motorists but also users of public transport, who, in developing countries, are lower-income persons; in addition to lengthening their travel time, there is a possibly even more regrettable consequence for them, which is that congestion pushes up fares.

Nevertheless, a limited degree of congestion may not be altogether unacceptable. It is preferable to tolerate a certain level than to adopt measures which have an even greater cost. After all, congestion is a sign of activity, and trying to eliminate it altogether could entail disproportionate investments in the road network which could significantly prejudice various other kinds of socially beneficial ventures. While it is clear that acute congestion has direct negative consequences, it also has other more general and disturbing effects that loom over cities suffering from it.(Bull, 2004)[37]
In this case study I am going to examine and propose the most effective AI solutions and applications that will reduce traffic congestion.

4.2 Background

According to (Falcocchio and Levinson, 2015)[38] traffic congestion results from the imbalance between the supply of and the demand for transportation facilities:

- The supply is constrained by history and geography, by transportation management and operating practices, and by the level of investment on streets and highways
- The demand results from the concentration of travel in space and in time.

Congestion can be classified in two categories: recurring and nonrecurring;

- Recurring Congestion is the delay travelers regularly experience/expect during known travel times—such as the morning and evening rush hours
- Nonrecurring Congestion delay is caused by non-predictable (random) events that disrupt traffic flow. These include incidents such as vehicle breakdowns or crashes; road repair and inclement weather; special events that create sudden surges in demand such as the end of a sports event; and natural or man-made disasters. Nonrecurring congestion can either create new congestion (in the off-peak periods), or can increase the delay experienced during periods of recurring congestion.

Today the causes of traffic congestion are more specifically known and include (1) large concentrations of demand in time and space—including temporal surges in travel demand on roadways of generally constant capacity physical, operational, and design deficiencies that create bottlenecks, (2) traffic demand that exceeds roadway capacity, and (3) physical and operational bottlenecks.

Congestion generally increases with city size. This happens because activity concentrations are larger, and travel distances are longer as cities grow.

If all travel demand were evenly distributed among the various sections of the urban area, the traffic congestion problem would be a rare event. Similarly if all travel were evenly distributed to each hour of the day there would be little, if any, congestion. But travel demand patterns reflect the concentration in time and space of daily activities: where and when people work, shop, recreate, move goods and provide services. It is the peaking of these spatial and temporal travel patterns that contributes to the recurring traffic congestion problem.
Major activity and employment centers generate the highest concentration of traffic demand (trips ends per square mile) because of they are places of high development densities (people/employees per square mile). These centers include long established central business districts and the growing number of large suburban centers. Suburban mega-centers, mainly automobile dependent, generate heavy traffic volumes on major arterials and approach roads which are typically congested. And even where major centers are well served by public transportation, traffic density is high, and congestion is also a problem.

Growth in population, employment, and car use (vehicle miles of travel—VMT) increase congestion on streets and highways where capacity growth has not kept pace with growth in VMT i.e congestion increases when the investment in transportation facilities fails to keep up with the growth in travel.

Bottlenecks are perhaps the most common cause of congestion. They result from the convergence of a greater number of lanes in the upstream roadways than are available in the downstream roadways. Bottlenecks delay is typically found in hours of peak flow where the number of lanes converging on a roadway, bridge or a tunnel exceeds the number of lanes these facilities have. An example of a bottleneck is shown in Fig. 4.1, where traffic from three lanes is merging into one lane. Bottlenecks are also created by roadway incidents that reduce block travel lanes and restrict traffic flow, or they are created by bad weather conditions (e.g., ice on a bridge), a work zone, poorly timed traffic signals, or driver behavior.(Falcocchio and Levinson, 2015)[38]

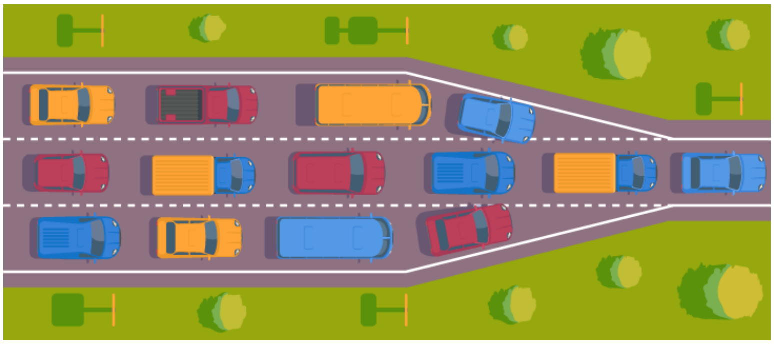


Figure 4.1: *Bottleneck example.*
[39]

4.3 Reducing road congestion

There is no doubt that the causes of road congestion is a combination of infrastructure barriers and human control of driving. In this case study I am going to focus on the human side of the problem. I believe artificial intelligence is an obvious solution to this problem. Over the years different AI solutions have been tried to reduce this problem. In this section we are going to go deeper into these solutions.

Adaptive cruise control (ACC) provides assistance to the driver in the task of longitudinal control of their vehicle during motorway driving. The system controls the accelerator, engine powertrain and vehicle brakes to maintain a desired time-gap to the vehicle ahead. An ACC system can provide considerable reductions in the variation of acceleration compared to manual driving. This indicates a potential comfort gain for the driver and environmental benefits.(Marsden, McDonald and Brackstone, 2001)[40] This system still requires an alert driver to take in their surroundings, as it only controls speed and the distance between the driver and the car in front of him. This control system is a solution that reduces unnecessary stop and acceleration on the road which is one of the causes to congestion. Currently I do not believe that this technology reduce the congestion to the extent that is desirable because of the number of cars on the road that uses this technology is far below what is required to see a huge reduction in road congestion.

According to (Schaub et al.2013)[41] automotive navigation systems (ANS) have matured into a mainstream technology. While integrated ANS are mostly found in middle- and higher-range cars, cheaper portable navigation devices enable the addition of ANS into any vehicle. A navigation system's purpose is to support drivers in traveling from location A to destination B with route guidance. Modern

ANS not only visualize the routing process on maps but contain additional features, like text-to-speech or advanced lane guidance with 3D visualization. Many devices can also receive up-to-date traffic information via the GPS (Global Positioning System), TMC (Traffic Message Channel) and similar services. This technology will give drivers current information and alternate routes to avoid high congested areas and therefore in my judgment this is a factor that will help reduce traffic congestion.

In Hamid et al.(2016)[42] it is stated that one of the major problems of road traffic globally is road congestions. In addition to the collision risks due to the heavy traffic congestions, according to the Bureau of Transportation Statistics of United States, the aforementioned problem is responsible for about a third of vehicle carbon emissions in the United States. One of the technology which was introduced to help in reducing the traffic congestion is vehicle platooning. It is an interdisciplinary system which aims to improve the fuel consumption, mileage as well as enhancing the safety of a vehicle. Vehicle platooning is a centralized system where several autonomous vehicles in close space, are computer controlled thus creating a vehicle platoon which will provide essential solution to the traffic congestion and air pollution problems. The communication between the vehicles in the platoon enables the vehicles to exchange the information about their surroundings, thus cooperating to improve their future navigations (Figure 4.2). In addition, the truck platooning is also introduced, to reduce the rate of truck accidents due to driver inattentiveness and drowsiness.

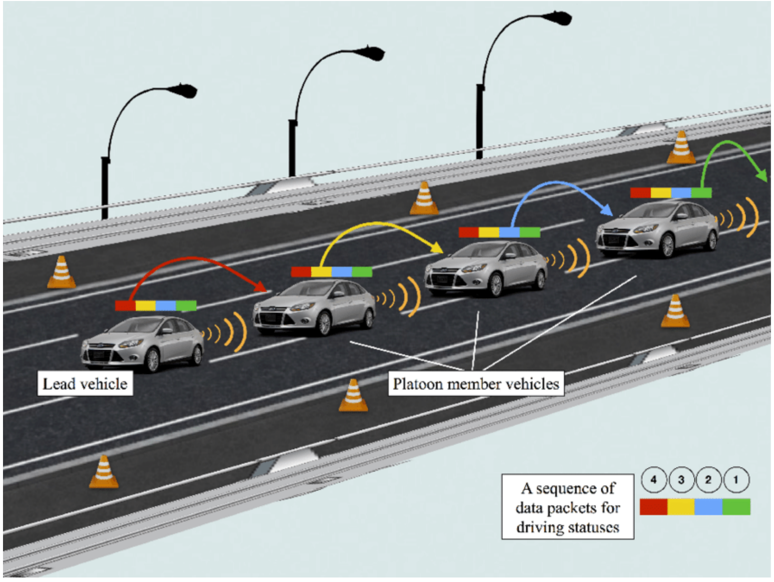


Figure 4.2: *Vehicle platooning*
[43]

The combination of vehicle platooning concept with other ADAS systems such as ACC, will help in producing better collision mitigation technology. Besides, the information obtained from the leading vehicle of the platoon can help the vehicles to plan their longitudinal and lateral motions precisely. However, vehicle platooning remains a challenging concept to be implemented globally due to the needs to modify existing road infrastructure, which demands the collaboration between various sectors. Personally I believe platooning will reduce congestion drastically. A number of cars following the same speeds is an effective solution which will enable smooth traffic flow for both the cars in the platoon and the surrounding cars.

Intelligent Speed Adaptation (ISA) systems are in-vehicle systems designed to improve driver compliance with safe speeds. These systems can provide information on safe speeds to driver, warn the driver when they are exceeding this limit, or control brakes or throttle to prevent speeding.(Blum, 2012)[44] The effectiveness of this technology is in my opinion equivalent to the ACC where the speed is at a controlled level and hindering unnecessary variances in traffic flow.

Vehicular communication systems consist of a network, where the vehicles and environments are communicating nodes. They exchange information among each other for safety purpose and traffic information. Among the examples are the Vehicle-to-Vehicle and Vehicle-to-Infrastructure strategies. With the latest developments of Internet-of-Vehicle, which is a branch of Internet-of-Technology, the developments of Vehicular Communication System are progressing now more than ever. Vehicle-to-X (X refers to any medium which relates to the vehicle, e.g. another vehicle, infrastructure) enables the vehicles to communicate with each other and send the messages regarding the environments, traffic flow as well as the future appearing vehicle beyond the driver's limited visual range. The combination of this technology with Collision Avoidance Systems have been done in, and is proven to be helpful in warning the driver about the potential risks prior to the accidents.(Hamid et al.2016)[42]. In my personal judgment I believe that this is probably the most effective solution to this problem, which will solve problems in numerous areas e.g. help vehicles plan road trips and avoid highly congested areas.

4.4 Failure

While developing AI technology to combat problems associated with the road, there have been problems that have led to accidents. An example is the Tesla crash in 2016 with autopilot activated. Autopilot is an advanced driver assistance system with level 2 autonomy that enhances safety and convenience behind the wheel. When used properly, Autopilot reduces the drivers overall workload. It has 8 external cameras, a radar, 12 ultrasonic sensors and a powerful onboard computer which provide an additional layer of safety to guide the driver on the journey.

According to (Singhvi and Russell, 2016)[45] a Tesla Model S crashed in northern Florida into a truck that was turning left in front of it. The Tesla then ran off the road, hitting a fence and a power pole before coming to a stop.

Furthermore in (Shepardson, 2017)[46] it is stated that the man killed in a crash last year while using the semi-autonomous driving system (autopilot) on his Tesla Model S sedan, kept his hands off the wheel for extended periods of time despite repeated automated warnings not to do so. A view of the accident is shown on the figure below.

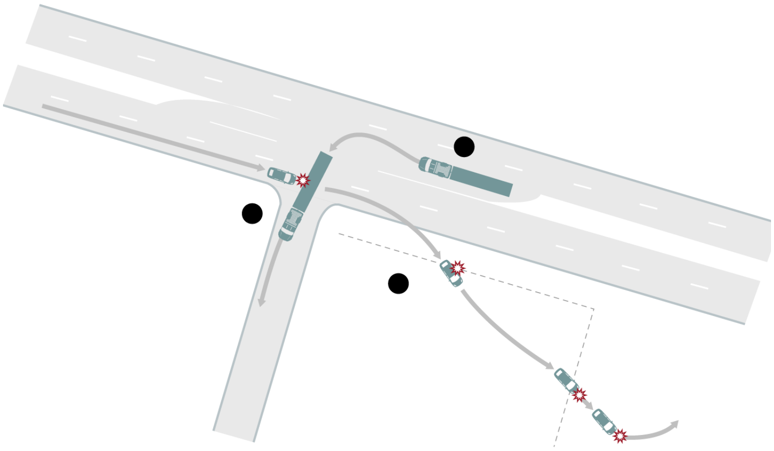


Figure 4.3: *Tesla crash 2016*
[47]

So in this accident researchers have concluded that the factors that caused this crash was over reliance on the adaptive cruise control feature that the Tesla car has. The Autopilot was not meant for a complete take over of vehicle control, but as an assistance to the driver, helping with maintaining speed and flow.

As a result to this and other accidents that have happened while drivers have used autopilot, an update was created. To ensure that drivers are not over reliant on autopilot. According to (Wattles, 2018)[48] Tesla created an algorithm controls in 2018 to ensure that Tesla vehicles warn their drivers to put their hands on the wheel. A message can pop up on the dashboard screen and chimes will sound. The notifications are triggered based on a variety of factors — including how fast the car is traveling, where it is in relation to other cars on the road, and how long it's been since the driver's hands were last detected. The warnings can escalate if they are ignored by the driver. With this software update, Tesla drivers will start receiving notifications more frequently, especially if they're driving at high speeds. Tesla crashes with autopilot has revealed limitations to the technology. The name autopilot can be very confusing, drivers can misunderstand the use of this adaptive cruise control. Tesla have received heavy criticism of their use of the name. According to (Hogan, 2017)[49] limitations to the autopilot include that the software should only be used on divided highways, as it isn't yet capable of responding to perpendicular traffic. Responding to cross traffic requires a lot more decision making than Tesla may want to take responsibility for. It's also only designed for usage in areas where lanes are clearly marked. The company warns against construction zones, especially after a viral video showed a Model S on autopilot slamming into a wall due to unclear lane markings in a work area. And because autopilot is driver assistance technology, not driverless technology. Vigilant and constant supervision is required.

The implementation of autopilot also brought many benefits that can't be discarded, according to (Brookhuis, Waard and Janssen, 2001) [50] the purpose of ADAS like autopilot is that driver error will be reduced or even eliminated and efficiency is enhanced. The benefits of ADAS implementations are great because of a significant decrease in human suffering, economical cost and pollution, since:

- driving safety will be considerably enhanced;
- many more vehicles can be accommodated, on regular highways but especially on dedicated lanes;
- high-performance driving can be conducted without regard to vision, weather and environmental conditions;
- drivers using ADAS can be safe and efficient drivers (cf. elderly, inexperienced drivers).

There has already been an large amount of investment in AI technology and autonomous vehicles. Companies are realizing that this industry has a large potential. Companies like Waymo, Uber, Tesla and even Apple are pouring billons of dollars in research and development of EV, AI and battery technology.

4.5 Investments

As stated by Holland-Letz et al.(2019)[51] investments in new mobility start-ups have increased significantly (Figure 4.4). Since 2010, investors have poured $220 billion into more than 1,100 companies across ten technology clusters. Investors invested the first $100 billion of these funds by mid-2016 and the rest thereafter. The automotive industry is shifting into gear as a broader definition of mobility takes hold. Driven by the four ACES trends: autonomous driving, connected cars, electrified vehicles, and smart mobility— automotive OEMs, suppliers, and new entrants such as tech players and venture capitalists are attempting to build strongholds in the emerging mobility ecosystem.
It is estimated that securing a strong position across all four areas would cost a single player an estimated $70 billion through 2030. It's doubtful any individual OEM could shoulder this level of investment alone, which is why partnerships and targeted acquisitions offer an attractive strategy for staying ahead of competitors.

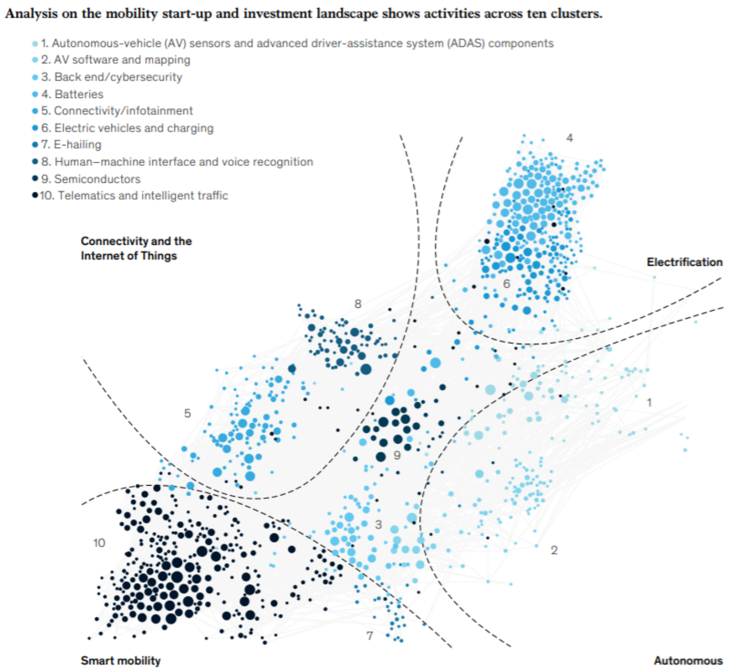


Figure 4.4: *Mobility investments*
[51]

In the recent years investments have dramatically grown we can see from figure 4.5 a comparison of the periods 2010–13 and 2014–18, when average investments across all technologies jumped sevenfold. The analysis reveals that more than half of the investment volume comes from large investments with transaction values greater than $1 billion, these are industry-shaping moves and include the mergers and acquisitions (MA) of established companies.

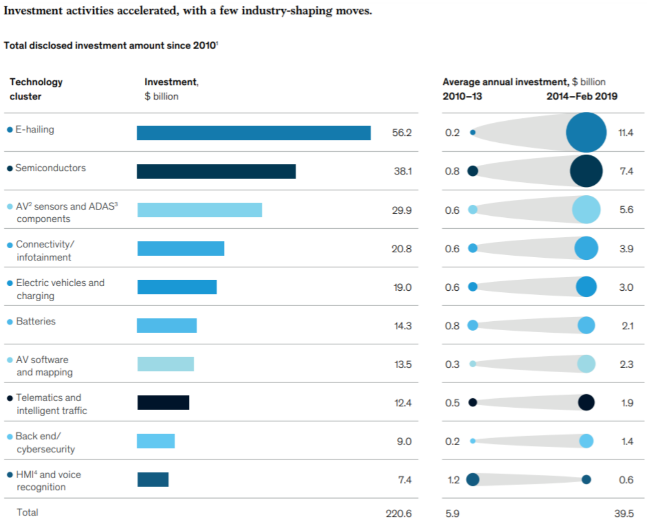


Figure 4.5: *Investment comparison*
[51]

Over a third of the overall investment in mobility went to companies in the United States, followed by China ($51 billion), the United Kingdom ($34 billion), and Israel ($18.5 billion, where $17.4 billion comes from investments into Mobileye). The next highest European country is France, in tenth position. Even though the European Union (EU), excluding the United Kingdom, receives only 5 percent of global funding, it contains 19 percent of all identified companies (Figure 3.6). Thus, average investment sums in Europe remain far behind those in the United States and China. This breakdown is similar when looking at the source of money as opposed to the recipients: the top investors come from the United States, Japan, and China, while the largest investor in the European Union is Germany, at only $4 billion. (Holland-Letz et al.2019)[51]

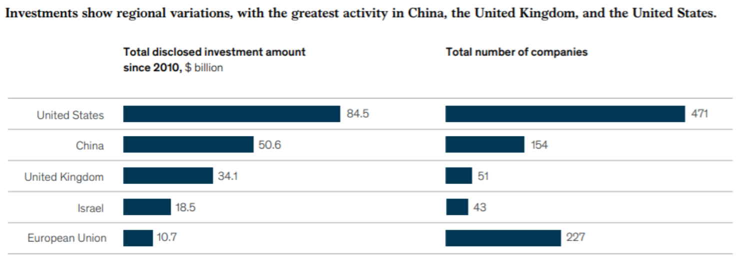


Figure 4.6: *Investment by countries*
[51]

4.6 Solutions

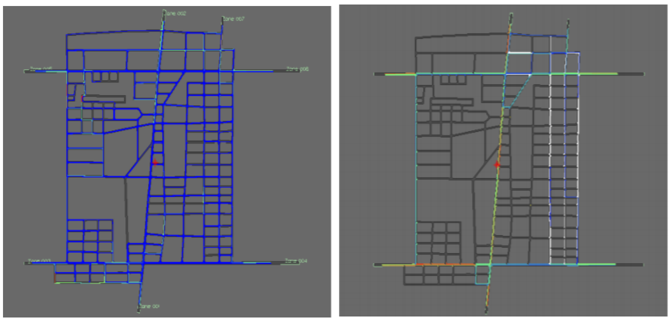
The best solution to reduce traffic congestion is with AI technology. More specifically fully autonomous vehicles with vehicle communication systems. These vehicles are more commonly known as automated vehicles. It is no secret that human driving and recklessness on the road is a major contributor to road congestion and pollution. Therefore I believe automated vehicles that are driven by algorithms that can detect patterns to traffic flow and communicate with vehicles, infrastructure etc. will reduce this problem.

According to (Piao et al, 2016)[52] automated vehicles have a great potential to change travel and transport fundamentally. Not only will the technology reduce crashes, increase values of travel time, and reduce energy consumption and pollution, but also increase mobility and accessibility for all. Several studies have been reported to explore the potential applications of automated vehicles in many areas of urban transport.

A fully automated vehicle would be capable of navigating in a road network, detecting obstacles in the surroundings, and running safely without human intervention. Several studies have been reported on the research and development of automated vehicles. Based on the studies, key features of automated vehicles can be summarized as follows:
Automated vehicles will avoid crashes caused by human errors which are believed to be the main reasons behind over 90 percent of all crashes such as driving under distraction, speeding, alcohol, drug involvement and/or fatigue. This will have a wide range of impacts on society including 1) avoid casualties to drivers and passenger, or and to other road users, 2) avoid loss due to damage of the vehicles, 3) reduce insurance premium cost for operators, 4) avoid traffic congestion and additional fuel consumption and pollution caused by the accidents. Automated vehicles will improve fuel economy and reduce emissions. On the one hand, automated vehicle technology promises to reduce energy use because of reduced

vehicle weight. Over the last two decades, vehicles have become increasingly heavy to meet more rigorous crash test standards. If crashes become exceedingly rare events, it may be possible to dramatically lighten vehicles. On the other hand, unlike human drivers often brake or accelerate too harshly, AV will improve fuel economy by controlling vehicle more accurately and consistently. For automated vehicles, no human driving is needed which will have wide range of impacts. Firstly, AV will improve mobility and accessibility for all, especially those too young or too old to drive. Secondly, automated vehicles allow 'drivers' to use their time in a vehicle more productively, for example reading, interneting, and telephoning/messaging. Thirdly, AV will remove labour costs of vehicle operation. Not only will the transport service providers (e.g. buses and taxis) benefit from reduced operating costs, but end users benefit from reduced travel costs as well. AV also promises to automatically locate itself and navigate in a network without human intervention. This will make it possible for automated vehicles to park themselves and then pick the users up later. On the one hand, such an attribute will obviate the need for nearby parking which enables redevelopment as adjacent parking lots becoming unnecessary. On the other hand, it will reduce waiting time and walk distance to access to a car.

In Olia et al. (2014)[53] the impact of communication and sharing travel time information among connected vehicles in a area in Toronto was modeled in PARAMICS. Connected vehicles were able to disseminate and receive real-time information data and therefore navigate through multiple routing options in the network; however regular vehicles had to choose among their familiar pre-set routing options. Figure 4.7 shows the vehicle distribution and the many routing options available for the connected vehicles and the very limited congested routing options available for regular vehicles in the model.



(a) For connected vehicles. *(b) For regular vehicles.*

Figure 4.7: *Routing options*
[53]

To assess the impact of connected vehicle on travel times, the travel time through three key corridors was analyzed, in corridor 1 travel time dropped from 14.4 minute to 6 minute (around 58% improvement) in the case of 50% market penetration of connected vehicles. Also the same pattern can be seen for corridor 2 and corridor 3, this is displayed on figure 4.8. To further study the travel time savings between origin and destination pairs, the overall trip travel time for all trips originated from traffic Zone 1 to Zone 2. Figure 4.8b shows the difference between origin-destination travel times for connected vehicles vs. regular vehicles in the network at different market penetration rates. As expected there is no difference between connected vehicles and regular vehicles origin-destination travel times at zero market penetration; and as the percent of market penetration of connected vehicles increases the overall origin-destination travel time for both connected and regular vehicle decreases. This trend continues to a certain limit (40% penetration) until all the vehicles are equally distributed into the network through the dynamic routing in PARAMICS. At this point vehicles would have distributed across the network with equal origin-destination travel times to an extent that do not differentiate between connected vehicles and regular vehicles.

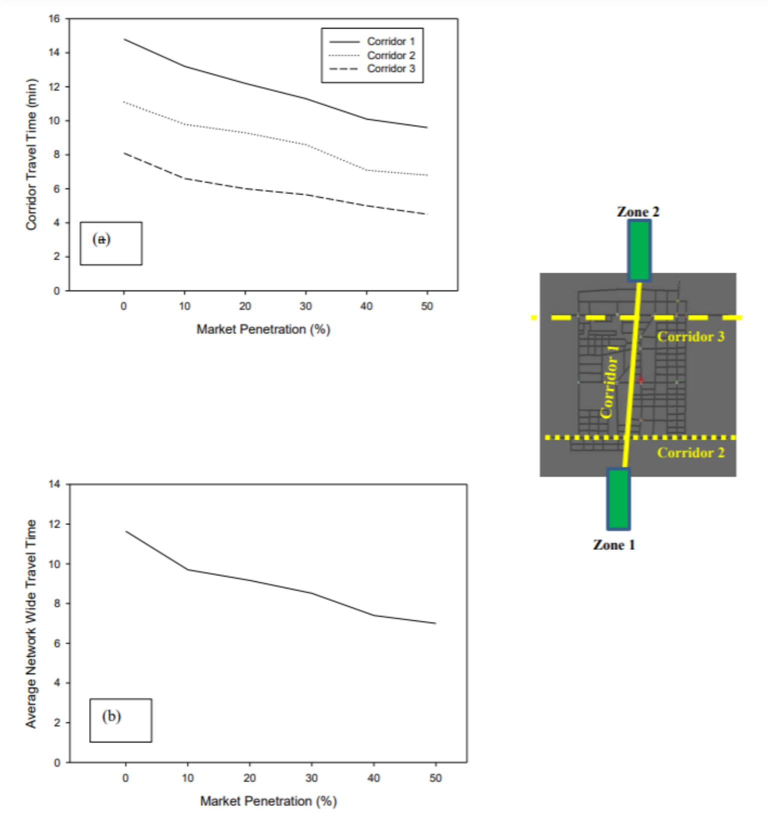


Figure 4.8: *Traffic analysis*
[53]

Figure 4.8b also represents average travel time in the network wide scale. From this graph it can be interfered that in general drivers will experience 35% less travel time when connected vehicles account for 50% of drivers. This interesting finding indicates that 1) an optimum market penetration (40% in this case) is only needed for the overall origin-destination travel times to be minimized and that it is not necessarily true that the higher penetration rate the better overall travel time for all vehicles, 2) not only can connected vehicles save their travel time, but also non-equipped vehicles can benefit and take advantage from freely congested routes. Travel time saving by developing market penetration of connected vehicles results from rerouting of enabled vehicles. In other words, connected vehicles have access to instantaneous travel time information for the whole network and in case of any congestion they can respond quickly and find the quickest path to destination. Figure 4.7a, and 4.7b show how connected and regular vehicles occupy network. Providing real time information with connected vehicles make them to diverge to alternative and less busy routes and leverage detours while regular vehicles mainly stick to corridors. This process makes the congested corridors less busy and reduces travel time while increase travel time for the minor routes. However in general both drivers on average experience less travel time.(Olia et al., 2014)[53]

As stated automated vehicles will help solve numerous problems beyond road congestion, like safety, mobility, cost etc. Therefore I can conclude that I believe the best AI solution to solve road congestion is the development of automated vehicles, which takes the control from the driver, with more safer and controlled journeys and access to more information.

4.7 Recommendations

There are numerous strategies for accomplishing the solution to reduce and possibly end traffic congestion. The most obvious solution is through investments in research and development. I believe that investment in AI technology, machine learning and algorithms is the way too achieve full autonomy in cars, and developing automated vehicles that will help reduce traffic congestion. As shown on figure 4.6 the U.S is the country that has invested the most in this technology and are the ones that have come the furthest. As the economy of China is growing at a fast pace they are closing the gap on the U.S in terms of both technology and economic output. Therefore the recommended strategy to achieve the widespread development of automated vehicles is through investment in research and development because this is an area where there is not sufficient amount of knowledge and information on.

Chapter 5

Discussion

5.1 Results

The master's thesis aim was to research different technological solutions in vehicles to reduce road congestion. It has also focused on the potential of artificial intelligence to transform and disrupt existing mobility. The overall goals of AI in vehicles is to achieve more sustainable mobility and to provide ability and accessibility to move freely without affecting essential human or ecological needs of the future generations. The concept of achieving sustainable mobility relates to sustaining economic, social and environmental pillars of the society.

The research has successfully covered the proposed research questions. To recap, artificial intelligence in cars has the potential to reduce road congestion and significantly improve efficiency in transportation of vehicles. With AI technology implemented and automated vehicles, in the case of the area in Toronto stated in chapter 4.6 a driver may theoretically reduce travel time by 35%. Road safety will certainly also be improved thanks to the technology, demonstrated by the decreased accident rates of cars with the implementation of autonomous driving assistance systems, as stated in chapter 3.2, even though the technology is only in its early implementation phase. Backed by several studies, it is possible that road safety can be improved even more when autonomous driving can be widely adopted on the roads with a high market penetration, mainly thanks to the AI with better, faster and more reliable sensing, decision making and action executing abilities.

As some other innovations, development of automated vehicles comes with obstacles that needs to be overcome, on the technical and societal perspectives. Failures like the Tesla crash in 2016 can occur. Which will diminish the trust the public have in the AI technology. External attacks on the computer software and vehicle information can lead to very serious damages. The technology readiness is also challenged by policy and ethical issues, like how the automated vehicle is going to choose between two undesired options, although the society will have to become familiar with the idea that in a near future, we could be surrounded with AV fleets of electric vehicles.

The automated vehicle technology will be a game changer in the competition for market shares that opposes the largest automotive groups worldwide. Large investments from large companies and countries are pouring into research and development. We are still far away from widely adopted automated vehicles. But a lot of research has to be done in sensor, connectivity and cybersecurity improvement to reach the goal of large market penetration of automated vehicles. But the strategy which will be used by the main actors to have a weight in this future market must involve ethics just as much as it does economics.

The purpose of this study was to make a state of the art of the AI technology perspectives and its impact on the road, society and automotive market. The results of the study are very promising and it shows that there are limitless possibilities and practical implementation of autonomous vehicles in day to-day life.

5.2 Suggestion for further research

There are numerous researches going on currently on artificial intelligence technology in vehicles but there is a large gap between technology and implementation, there is a need to conduct extensive research in several areas to reduce road congestion and solve other relevant problems, this will bridge the gap between the technology and its economical implementation.

This research was conducted in the early phase of implementation of autonomous driving technology, therefore the availability and variety of scientific and imperial data is limited, the lack of academic studies on the topic also limits the number of point of view on the AI technology. In this thesis there are some practical implementations mentioned, but as stated there are still numerous unexplored areas that need to be studied. The possibilities to develop business models with autonomous vehicles are limitless, as stated in 3.5 some researchers have suggested car sharing models or human-less delivery services, but the limitations and acceptance by the public have not been researched on a broader scale.

Several technical and social topics related to self driving vehicles are still unexplored and requires extensive attention from researchers and policy makers. One example is a major ethical topic, that til this day have not got a concrete solution e.g, “Who should be held responsible in the case of an accident”. Numerous studies, and interviews from researcher has gotten different answers, some say that the company should be held responsible, others say the user should be held responsible this is a debate on the global level and is a critical challenge for policy makers. Another unexplored topic is how regulated should automated vehicles be. This is a disruptive technology that doesn’t only give more mobility options to a broader population, but it has the potential to take away millions of skilled jobs in driving e.g drivers, truckers, even pilots when it becomes widely adopted. There is also an economical cost associated with it, the tax or fine revenues may decrease dramatically and this can have deep penetrating impact in the society too if these revenues contribute a large amount to funding social benefits or other government spending. There is a need to study the down side of this technology extensively, although a few blogs, articles and papers have discussed these topics briefly, but still a deep insight on these topics is required.

In the future, when automated vehicles are widely adopted, research on the effects of AI in vehicles can be conducted again. To find out how it will affect congestion, accident rates, pollution etc. With more relevant scientific data collected from actual operation of automated vehicles, the results will be more accurate and reliable, which will give a better view on the technology of automated vehicles. At present, the research may serve as a guideline to prepare for the inevitable future of autonomous and automated vehicles for all parties involved: customers, manufacturers, policy makers and public infrastructure managers. Meanwhile educating the public about all matters related to the technology would be beneficial, as it is fairly a new technology and under-valued to the public.

Chapter 6

Conclusion

To conclude this thesis provides and insight to possible solutions to solve road congestion, with AI technology. The research method was a qualitative research method that focused on existing research of AI technology in vehicles with limited scientific data. In general, AVs will most probably increase travel demand, which will result in increasing VMT. The average travel distance will also increase when AVs market penetration increases, because AVs will most likely attract travelers to travel longer. The average speed will increase when the market penetration increase. Hours spent commuting will decrease due to the connectivity and information exchange between vehicles and traffic conditions will improve, especially when the market penetration of AVs reach a high level. AVs will eventually help improve the traffic conditions and will increase traveler's willingness to drive. The result of this thesis shows that in this precise situation, innovation can on one hand improve everyday life of a lot of people, fewer accidents, reduce time spent commuting, give more access to transport to persons without driving license. On the other hand, it can reduce job numbers for drivers, it can be subject to cyber-attacks and can be subject to fatal technical errors. Since automated vehicles are still in the early stages of research there is a lack of data to back or prove the assumptions in the thesis. Therefore, this thesis can be used to understand AI technology in vehicles and generate new ideas in the development of these vehicles. It can be used to solve different limitations with this technology like trustworthiness, ethical problems, regulatory problems and companies can base their algorithms on recommendations from this thesis.

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