Preliminary Ethical, Legal and Social Implications of Connected and Autonomous Transportation Vehicles (CATV)

This document contains a literature review on the ethical, legal and social implications of the development, implementation, and maturation of connected and autonomous vehicles (CATV) in the United States market.

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Introduction

Connected and autonomous vehicles (CATV) have received a great deal of attention in the recent past, especially as industry heavy hitters like Google, Apple and Intel move forward with development and testing, even putting automated vehicles on public roads in the past two years. However, for lawmakers to design serious policy for successful implementation of CATV, a series of ethical, legal and social issues and their impacts must be evaluated.

Autonomous vehicles are currently in various stages of development. Many technology and automotive companies having been working for many years to develop autonomous vehicles, but have met resistance socially and technically. The current trends are moving away from automation that would integrate the human driver, and towards automation that is fully functional while the human passenger is a passive participant and has minimal if any responsibilities for operation. Some estimates suggest that fully autonomous vehicles may be integrated into normal traffic within the next ten years, while conservative estimates put that kind of success closer to the year 2050. Regardless of the timeline, there are several barrier-to-market issues that must be addressed. These issues have been cautiously discussed in current research, but a comprehensive address of these topics and their impact on CATV success has yet to be fully realized.

The following review highlights these issues, as seen through the lens of current research, public interest and societal need. The diagram below shows the relationship each issue has to each other, as well as to ethical, legal and social impacts. These classifications are subjective and are likely to change as the field research grows and develops.

Privacy

Connected and autonomous vehicles will run extremely sophisticated and advanced on-board computing systems, all of which would have the ability and capacity to transfer enormous amounts of data about the user and their whereabouts to third parties. Vehicle makers, especially those considering autonomous vehicles, are currently moving on-board technology towards vehicle context awareness, which means a vehicle is aware of itself, its actions, location, history, habits, surroundings and neighborhoods, including other vehicles and their locations. Without this capability, an autonomous vehicle would not be functional, nor would the passengers be capable of passive participation (i.e. ride in autonomous vehicle without engaging the system).

Autonomous vehicle on-board computers will have the ability to process and connect with Bluetooth, Ethernet, USB, and IEEE 802.11 interfaces, and will be capable of recording and transmitting these data points. Using technologies such as front, side and rear radar sensors, odometric sensors, LIDAR sensors, machine vision, event data recorders (similar to a black box on aircraft), GPS receivers and transmitters, and a communication platform by which vehicles can share information with each other, every vehicle's location and transportation history will be known and can be easily accessed (Hubaux, Capkun, & Luo, 2004).

Additionally, the government may require all vehicles to be electronically registered, as they are currently required to be paper registered. However, in an autonomous vehicle environment, technology may allow the government to read these electronic signatures from an autonomous vehicle at any time while driving, and will therefore be able to access any vehicle's location at their discretion (Petit & Shladover, 2015).

It is not known who will own this information, which will have access to it, how it will be accessed, or if it can be protected. It is likely that any autonomous vehicle will be required to communicate with a variety of other computer systems (infrastructure, other vehicles, the manufacturer, maintenance), and it is conceivable that an individual's location information and history would be available to any person accessing any of those systems at any given time. Additionally, it is not known if that data would be owned by the manufacturer, by the department of transportation, by the owner, or by another unnamed third party. If any party other than the vehicle owner owned the data, it could easily be sold for profit, research, or misuse without the permission of the user. Furthermore, it will be possible for any stakeholder to access the information, regardless of ownership, through legal means (working for a stakeholder) or through illegal means, such as computer hacking.

For the consumer, their data may be accessed, viewed, and used for a variety of reasons, for many of which they will not individually wish to give their consent. However, there is a challenge in educating the average consumer on what rights to privacy they may be

forfeiting in using connected and autonomous vehicles, and/or how they can protect their information. It is also possible that the user will be forced to accept that they have no rights to privacy at all, and their private information, such as their location at any given time, human data identifiers (fingerprints or retinal scans), crash data or where they have traveled in the past, will be available at will to stakeholders (Lin, 2013).

Solutions to these privacy concerns are both technical and legislative. Infrastructure design and safeguarding measures can be put into place to protect data both within the vehicle and at stakeholder sources, but the key element for privacy control will be creating laws that make any breach of data or misuse of data illegal.

These privacy issues posed by connected and autonomous vehicles have yet to be resolved, and present an ethical and legal issue that must be resolved and legislated.

Security

Security of CATV is related to the privacy implications. However, the results of poor security for an autonomous vehicle system have different outcomes that may be far less desirable and far more serious for all stakeholders.

Petit and Shladover (2015) describes the many ways that connected and autonomous vehicles are vulnerable to security breaches. Because these transportation vehicles will be, by definition, equipped with highly connected technology, including Wi-Fi connectivity and Bluetooth, and will be driven not by a human but instead by a computer, they are open for hacking attacks.

It would be possible for intruders to access the system to create fake messages to vehicles (creating hazards where none exist, blocking sensors so vehicles think a situation is safe when it is not), fake messages to infrastructure sensors (changing stop lights inappropriately, jamming GPS signals), or may even interfere with the mechanical proprieties of the vehicle itself, telling the computer to apply the brakes randomly, speeding up or slowing down without need, or may interfere by programming the

computer to ignore sensors and communication boxes in the vehicle and to essentially ignore commands. These scenarios could result is extremely dangerous traffic situations, and could cause very serious consequences for human users.

In order to avoid these dangerous situations, a foolproof GPS system must be created and an unhackable computer infrastructure must be built and designed (Hubaux et al., 2004). This is, however, challenging, extremely expensive and may be highly unlikely or infeasible. Nearly every computer-programmed device created has shown its vulnerability to hacking, and it is not likely that a commercial viable system (i.e. affordable) would be truly unhackable (Lin, 2013). A more feasible route may be a multi-tiered verification method, where redundant systems would exist as checkpoints for all contact points between computer systems. If data points were not the same within error tolerances, the vehicle or system would shut down and lock up to avoid further infiltration from undesired data sources. This kind of high-redundancy infrastructure exists today in aviation (Hopkin, 1991). Outfitting large-scale transportation networks, such as highway systems, with such comprehensive redundancy checks to ensure data accuracy would be a costly but mandatory venture for real CATV implementation.

Additionally, autonomous vehicles will be based on a large computer system that has ultimately been programmed to react to situations in specific ways, based on the inputs it has been fed from the environment around the machine. While the programming will be a highly complex, rule-based set of algorithms, every scenario ultimately comes down to a final "if-then" statement, where a maneuver or command is executed. If these mechanisms and programming rules become known, other drivers or maliciously aligned people, may attempt to "game" the system and can create dangerous situations by playing these programming rules against each other (Lin, 2013).

Tesla released an "autopilot" function on their Tesla Model S in 2015, which employed a forward-facing camera, radar, 12 ultra-long-range sensors, and a series of high-speed processors. It was said to be capable of straight-ahead highway driving (i.e. no complex scenarios), and was released with the warning that it was not an autonomous vehicle, but

simply an autopilot function for standard, predictable driving. Drivers using the system posted a variety of experiences and reviews online, showing that they were able to ignore warnings and were able to manipulate the vehicle to actually swerve into oncoming traffic by doing so (Berman, 2015). This is an example of how a rules-based programming can be manipulated for non-desirable outcomes that could possibly put human life at danger, particularly if someone were able to hack into the CATV system to exploit these weaknesses.

There is additional concern for the risk of cybersecurity attacks on non-cooperative autonomous systems. Non-cooperative systems would be vehicles that are fully automated but do not have the capability to communicate and receive input from other vehicles or the surrounding infrastructure. The risk of danger may grow here, especially in the instances when the driver is unable to override a malfunctioning system in a safe amount of time due to disengagement from the driving task. This difference in capability has implications on the vulnerabilities of the vehicle, and non-cooperative autonomous vehicles may become ripe targets for hacking and/or security breaches.

Additionally, there are a variety of types of potential security threats: internal vs. external, malicious vs. rational, active vs. passive, local vs. extended, intentional vs. unintentional. An internal attacker is one that is analogous to a mole in an organization. They are considered a member of the network and could communicate with other members, while an external member is an intruder on the network. An external member is more limited in the diversity of attacks they can conduct, but are is still able to eavesdrop via the communication channels. A malicious attacker seeks to disrupt the functionality of the system itself and pays no attention to costs or consequences, while a rational attacker is more predictable in behavior, as they seek personal gain. An active attacker is one that sends signals to perform an attack, while a passive attacker is one that simply eavesdrops on communication. Local vs. extended attackers differ solely on the scope of their attacks. Extended attackers control several district entities of the network. Lastly, intentional attackers actively have an intent to breach a network, while

unintentional attacks are those that are not the result of human intervention, but rather a result of a malfunctioning equipment (e.g. sensors).

There is a concern regarding the ability of drivers to be able to respond effectively when the automated system has reached its limits. General Motors found that after a period of 5 to 30 minutes of being completely dependent on the automation system, drivers typically disengage from the driving task and become merely passive passengers. Therefore, even when the system can identify a threat and warns the driver that the autonomous function will disengage and the driver is expected to take over manually, the driver may not be capable of regaining control of the vehicle within a reasonable time interval. Additionally, Petit and Shladover (2015) discuss how effective data fusion from multiple sources has the potential to override a cyberattack. This would only be the case when multiple redundant points of data input are available, which would allow the system to determine the accuracy of these data sets, both individually and together, against real world feedback. Furthermore, connected automated vehicles may use communication channels with other automated vehicles to determine and verify accurate information as an additional layer of redundancy. However, it is critical that the system is more skeptical of accepting this information at face value as compared to information obtained from sensors onboard since the information obtained from other vehicles may be the subject of attack or already be corrupted.

An example of how autonomous automated vehicles would benefit from incorporating cooperative elements is how the vehicles simply operate on line-of-sight technology and cannot see through objects or corners. For example, when travelling up a hill, the vehicle cannot see, and therefore, cannot assess oncoming traffic or infrastructure and would rely independently on its GPS location and map to plot its upcoming trajectory. Hence, autonomous automated vehicles would benefit from receiving road data from other connected vehicles that have traveled ahead to determine the best course of action.

The idea of an automated highway system was also proposed. It would consist of all cooperative and connected vehicles. Such a system would allow for greater predictability

and different security measures. A stable network would enable symmetric cryptography, which is more efficient than the current asymmetric cryptography system employed. Platooning is another example of applying a group-signature scheme.

Petit and Shladover (2015) also highlighted spoofing with respect to global navigation satellite systems (GNSS) - which plays a key role in positioning vehicles on accurate maps. Injecting fake messages (which could result in inappropriate action, such as accelerating or braking) is likely to be the most dangerous attacks that would produce the most severe results. This kind of security risk has also inhibited the ability of air traffic controllers to move away from radar, which is less accurate, and into using GPS to manage air traffic. The inability to know with certainty that the GPS has not been hacked or manipulated delivers an unacceptable amount of uncertainty to the system, and this has not yet been overcome. The offered solutions to these problems for autonomous vehicles, called selective availability and/or anti-spoofing modules (SAASM), are expensive and access is restricted for the general population.

Bonnefon, Sharriff, & Rahman (2017) shed light on the "social dilemma of autonomous vehicles" which refers to the moral decision-making algorithms which govern the behaviors of autonomous vehicles in situations of unavoidable harm, such that the vehicles will be faced with the decision to either sacrifice the life of the passengers for the greater good of pedestrians (utilitarian mechanism) or protect the life of the passengers at all cost regardless of the consequences to pedestrians. Despite the low probability of such an event occurring, mechanisms to act in these events must be regulated before becoming available for market sale. A discussion of the ethics and moral principles guiding autonomous vehicles must ensue. In surveys about the ethics of autonomous vehicles, respondents rated utilitarian autonomous vehicles - those which minimize casualties and may sacrifice the passengers lives to accomplish these goals - as being the most moral. However, a free-rider problem presented itself in that the participants significantly preferred to purchase autonomous vehicles that were self-protective in all circumstances, especially when faced with hypothetical situations in which a co-rider was a loved one. Passenger sacrifice was not approved when only one

pedestrian could be saved, but approval of passenger sacrifice increased as the number of lives that could be saved increased. The implications of this line of research is that utilitarian mechanisms are systematically morally sound and approved of, however they are likely to discourage buyers.

Licensing

It is not known if human drivers will need to maintain a current driver's license only, or if another kind of certification will be necessary to be the human operator or monitor of a connected and autonomous vehicle. Current state legislation suggests that a secondary, specialized operator permit will be required for individual operation of a CATV.

California and Nevada currently have legislation that allows a permit to operate a driverless or autonomous vehicle to be obtained, for testing purposes only. As of press, permits have only been granted to Google, Audi, Continental and Mercedes Benz for testing on public roads. California governance has instructed the DMV to enact stricter oversight on anyone applying for and granted a permit to operate CATV. This is done via public hearings. Both state's certifications require the companies provide record of 10,000 miles driven by the autonomous vehicle on private roads, and demonstration of the vehicle's capability in complex situations, such as driving around cones, approaching and passing a bicyclist and passing through school zones during speed-limited time frames.

Similar legislation is pending in addition states, such as Georgia, Hawaii, Louisiana, Maryland, New York and South Dakota, but have yet to set specific standards. This lack of standardized framework for obtaining a permit to test CATV presents a problem for CATV manufacturers, as they are faced with a mountain of regulatory uncertainty and overlap, where designing a CATV that is certifiable in one state may not be allowed in another (Fagnant & Kockelman, 2015). This kind of uncertainty and inconsistency makes the cost of these vehicles extremely high. For market entry of road-approved vehicles, standards for a license to operate them on public roads must be consistent across state lines.

Current laws allow licensed drivers in one state to operate motor vehicles in all states through reciprocity agreements. However, the law has been interpreted that this would not include autonomous vehicles unless the individual had a kind of explicit CATV license, however, this legal language has not been made clear. All legislation up to this point has been directed at autonomous vehicle testing on public roadways, not for individual citizens to operation these vehicles as personal transportation. It has not been made clear how personal licenses or certifications would be handled, and this legal ambiguity presents a barrier to market (Smith, 2014).

Additionally, if individual drivers are required to obtain a secondary, more specific operating license for autonomous vehicles, this could be a social barrier to participation, particularly if it has additional cost associated.

While some states have discussed what licenses will be required of "drivers" of CATVs, individuals have also discussed whether the CATVs are the entities requiring licenses. McChristian and Corbett (2016) explain that CATVs should be required to go through hefty requirements before being licensed to drive on the roads. They especially believe that the pattern-recognition software in the vehicles should be thoroughly tested. Comprehensive standardized tests for new vehicles entering the market should also be implemented to protect the public most effectively. Other individuals provide different reasons for requiring self-driving cars to be licensed:

- Sensing hardware, spatial maps, and software algorithms will vary among manufacturers of self-driving vehicles, resulting in variability of on-road performance—as is the case with humans.
- Visual and sensing performance of self-driving vehicles in inclement weather is not yet sufficient.
- Visual-pattern recognition is a potential problem for current sensing systems in self-driving vehicles.
- Current self-driving vehicles have not yet been tested thoroughly under a variety of demanding conditions (e.g., in snow).

- On-road performance of some current self-driving vehicles is not yet perfect, even in good weather.
- Self-driving vehicles will face, on rare occasions, ethical dilemmas in their decision-making. (Sivak and Schoettle, 2015)

Sivak and Schoettle (2015) further state the current graduated driver licensing (GDL) systems that American citizens must take part in to obtain a driver's license might not be applicable for CATVs. CATVs cannot necessarily apply the experiences gained under one set of driving conditions that required certain programmed capabilities to a different set of driving conditions that requires different capabilities (i.e. applying lessons learned while driving during the daytime to driving at night). A GDL system would only work for CATVs if the license allows the vehicle to drive under the conditions it is specifically programmed to drive under (i.e. daytime and dry roads), and the license can be "upgraded" when new software becomes available.

One example of a possible licensing law for CATVs is what is currently in place in Nevada (McChristian and Corbett, 2016). NAC-482A mandates that CATV drivers must obtain a certificate known as a "certificate of compliance," which identifies a specific location where the CATV can be tested. Comparable to human-driven cars, CATVs must have special temporary license plates. Furthermore, the law states that the car must be occupied by two people always the car is being tested. In the future, this law would likely need to be updated if CATVs were to become commercially available. However, this law nevertheless demonstrates one way in which users can be licensed to operate CATVs.

Insurance & Liability

CATV with level 4 or 5 automation will be designed and fully programmed by the manufacturers, and will likely receive no input from the human user while it is operating. This raises the issue of liability in the event of an accident. In the event of a CATV killing a pedestrian, or getting into an accident with another CATV, it is not known if the human owner will be considered liable for this damage and/or loss of life, or if the vehicle manufacturer will be held liable.

In theory, the CATV will always behave ethically in a way that would protect the owner from liability (Goodall, 2014). However, programming bugs, machine fault or failure are all possibilities that cannot be discounted, and such an argument also assumes that protection from liability equates to ethical behavior, which is not always easily interpreted.

There may be pushback from insurance providers as well. It may be a challenge to convince insurers that the technology is safe and works properly, and this may result in extremely high premiums for CATV users, which may discourage market penetration. Additionally, even with near-perfect automation, crashes will be unavoidable. In the current environment with human drivers, humans are not held at fault for conditions beyond their control (a deer jumps out in-front of them, road is unexpectedly wet causing the vehicle to hydroplane), even if their reactions are not considered best judgment. However, CATV should be equipped with technology to help them make better decisions in a faster amount of time. Because of this, it could be possible for CATV to be held liable or responsible for accidents significantly more often than human drivers are held liable. This ultimately brings to bear a larger, philosophical question of "who is the driver," as current regulations refer specifically to the human driver. These standards will likely need to be updated to maintain consistent expectations for insurers, manufactures, and passengers.

Beyond insurance premiums, this could cause problems in court. It would not be possible to sue or convict a machine, but it would then be possible to potentially sue or convict the computer programmer who made the vehicle. This kind of legal issue would highly discourage any company from manufacturing CATV, as their legal exposure would be completely unmanageable. Additionally, there is no proliferation of case law around automation or autonomous vehicles, so precedent would be challenging for courts to apply (Campbell, Egerstedt, How, & Murray, 2010; Fagnant & Kockelman, 2015; Schellekens, 2015).

One difficulty that insurance companies will face once more autonomous vehicles are on the roads is a lack of data. Actuaries at insurance companies require large amounts of data to determine risk-related probabilities (Noguchi, 2017). Because CATVs do not share the same risks as human-driven vehicles, insurance companies will not be able to immediately calculate appropriate policy rates. This issue could cause higher insurance costs for CATV owners or financial losses for insurance companies, depending on whether the risk projections are over or under. To alleviate this issue, car manufacturers should standardize their data collecting procedures regarding the safety and performance of CATVs. Standardized data will help insurance agencies and other stakeholders better analyze the risks of this new technology.

In 2015, sixteen states had introduced legislation related to autonomous vehicles (McChristian and Corbett, 2016). Just as human-driven cars are regulated on a state-by-state basis, every state will also need to decide upon CATV-appropriate regulations. Beyond the state licensing laws previously discussed, states might also need to determine who should be held liable in the event of an accident--the driver or the manufacturer (Noguchi, 2017). For example, Michigan has already passed legislation stating that CATV manufacturers are to be held liable in the event of an accident. Other states' laws include products liability protection for the vehicle manufacturer when the seller or user modifies the CATV (McChristian and Corbett, 2016). Some lawyers have concluded that these decisions regarding liability will need to be determined on a case by case basis in the courts (Noguchi, 2017). These cases will also help insurance agencies better understand how to price policy options for CATVs.

McChristian and Corbett (2016) cite a 2016 RAND study on CATVs that proposed that a new form of insurance, "no-fault automobile insurance," might be necessary in the future. If the driver is not responsible for the accident at hand, a product-liability lawsuit could be filed against the manufacturer. This type of lawsuit is costlier in terms of money and time than most car crash lawsuits, which means this no-fault form of insurance would allow victims to be compensated quickly. People envision this form of insurance to

resemble the federal National Childhood Vaccine Inquiry Act that compensated individuals who faced adverse side effects after receiving a vaccine.

Because of the technology these vehicles are equipped with, CATV insurance ventures into unchartered territory. Not only is this technology more expensive to repair and replace than most damages that would occur after a human-driven car accident, but this technology has the potential to be hacked. This hacking risk must be considered by insurance companies and state legislators to determine both policy prices and how these cases should be handled in court. Another way auto insurance might change with the advent of CATVs is that it might be sold with the car, which means the cost of the CATV will rise to address this. Furthermore, auto insurance companies would likely be hurt in the process as the CATV manufacturers become the purchasers of auto insurance, meaning fewer auto insurance purchases and plans.

States will also need to determine if CATVs must be required to be insured by their owners. The UK has already decided that CATVs must be insured by a policy that covers accidents that occur when either the human occupant or the vehicle itself is in charge ("Self-driving", 2017). Comparable decisions will need to be made on a state-by-state basis in the United States.

Infrastructure and Mixed Automation Environment

The concept of autonomous vehicles on public streets has a gradient of automation levels at which they will operate. Level 0 is no automation. The state of society and technology on currently vehicles has already passed level 0, as many vehicles employ assistive driving and parking, and vehicles like Tesla have autopilot functions. Level 1 is the autonomy of one primary control function, such as parking, lane-assist, or autonomous braking. This is the current state of public vehicle traffic. Level 2 is the autonomy of two or more primary control functions. These should be working in unison to relieve the driver of managing that function completely. We are not currently in this stage, as no automated functions in vehicles today completely take over the task with no

needed intervention from the human driver. For example, Mercedes has a highly developed parallel parking function, but this automation could not park a vehicle into a normal parking spot. Level 3 is limited self-driving, where the driver gives all driving function over to the automation in certain traffic conditions, such as straight highway driving, but is expected to be available for control with a warning. Level 4 is full automated driving, where the driver is not expected to be available for control at any time. Level 5 is full self-driving with no human interaction whatsoever. The autopilot for Tesla would be considered Level 3, but both Tesla and Google have announced plans to release vehicles that operate at a Level 4 of automation. Theoretically, traffic could operate as a mixture of all levels, or in a mixed capacity, where vehicles have ranging levels of automation.

For autonomous vehicles to operate on public roads with any kind of regularity, in either a mixed environment, where autonomous and human driven cars operate together, or in a totally autonomous environment, infrastructure will need to be re-evaluated. Different kinds of traffic patterns may be necessary, taking the programmed traffic rules into account, and different types of sensors, cameras, speed monitoring, parking structures, and other types of city planning may be necessary. The costs of infrastructure updates are not yet know, as these kind of investments would only be needed after a fully approved CATV were sanctioned by the governing bodies and the department of transportation for commercial use on public roads (Greenblatt & Shaheen, 2015).

Mixed transportation environments pose some safety risks, as vehicles will not be able to communicate with each other, and the style of driving between an autonomous vehicle (calculated and cautious, still gathering data and still learning from new situations throughout the lifetime of the vehicle) and a human driver (fluid, more aggressive, adaptable) may cause issues. As seen in the first major Tesla accident with autopilot, the vehicles were not capable of communicating with each other, as the human-driven truck had no connective capability to the self-driving sedan. Despite the human error from both drivers and the use of the system outside of the determined operating conditions, if the

vehicles were connected, it is likely their intentions would have been known to each other and both vehicles could have maneuvered to avoid the crash with this knowledge.

One plan for mitigation of these kinds of issues would be to have dedicated autonomous vehicle lanes or infrastructure, where autonomous vehicles would be separated from human-driven traffic with no ability to cross-over or intermix. There would likely need to be a "transition road space" where drivers would switch their vehicles into autonomous mode before merging onto the dedicated infrastructure, and this area would be mixed mode. However, it would likely be smaller and more controlled, so risks could be minimized or mitigated with more care (Surakitbanharn, 2018).

Economic Impact

The economic impact of CATV has been evaluated to determine both the barriers to entry and the benefits to society. (Fagnant & Kockelman, 2015) estimate that annual economic benefits could reach $201.4 billion dollars with a 90% market penetration (~65.1 million vehicles) of CATV. This includes the analysis that 21,7000 lives would be saved each year due to a reduction in human error and 4.2 million fewer accidents would occur each year. However, when this cost savings is reduced to the individual benefit, each person operating a CATV would likely only be saving $960 per year. Some less tangible benefits can also be quantified, such as time-savings due to reduced traffic congestion and fuel savings. Each year, a person operating a CATV would be likely to save $550 on these items, and on items such as parking, each CATV would likely save about $250. Overall, each CATV owned would save that person about $1760 per year.

However, the technology is extremely costly. If CATV were sold today, they would cost well over $100,000 per unit, and the economic costs would far outweigh the benefits. For the benefits to be realized and impactful, the vehicle would have to cost less than $37,500. It is estimated that with large-scale mass production, the price of these autonomous vehicles could fall to between $50,000 and $25,000 (Fagnant & Kockelman, 2015). The premium paid by CATV owners would likely start at around $10,000 more than a traditional vehicle (Fagnant & Kockelman, 2015; Greenblatt & Shaheen, 2015).

This is likely to drop to just $3500 within 20 years of the beginning of mass production. For example, a top-of-the-line 2018 Toyota Camry is priced at $34,000, so an autonomous driving version would likely be priced at around $44,000.

The average new car in the United States today costs $31,400 (Mays, 2017) and studies suggest that the average American family cannot afford a car at this price point (Carrns, 2016). While over 37% of people polled said they would definitely or most likely buy an autonomous vehicle once they became available, that participation value dropped to just 20% when those same people were told they would be required to pay a $3000 premium in order to purchase an autonomous vehicle. Annual ownership and operation costs (including maintenance, fuel and insurance) are estimated to cost from $6,000 to $13,000, and the current cost of ownership and operation today for a non-autonomous vehicle averages at $8,558 per year (Reed, 2017). The high price and price premium compared to a traditional vehicle will likely be a barrier to market entry and penetration, and the economic benefits described at the 90% penetration rate will be difficult to achieve because of these price and cost concerns.

Large government incentives, like those given to hybrid or electric vehicles, may help ease the price premium burden on the average consumer to aid in market penetration for full economic benefit.

There are many CATV adoption rate studies, all of which aim to predict the variables that will affect the rate, and to determine the relative significance of these variables so that the predictive model can be adjusted as more information becomes available on the determining variables. M. Lavasani et. al (2016) build a method for predicting this rate for fully autonomous vehicles using a classical Bass Diffusion model, popular in predicting new product market penetration, where each of the variables are given a value that is reasoned based on adoption trends of previous innovative new technologies, and accounts for additional factors specific to fully autonomous vehicles. Because of potential ride-sharing applications of autonomous vehicles, the usual metric – used for conventional automobiles – of individual based market size is changed to be household

based; this allowed them to assume typical US adoption rates for similarly revolutionary new technology, which has a market size of 75% of households, estimated to correlate to approximately 87 million vehicles. Using these values and assuming fully autonomous vehicles will enter the market in 2025, the model predicts a slow increase until about 2035, then a steep change that reaches the market saturation of 87 million vehicles sold in the year 2059, which is congruent with a very popular 2014 study by T. Litman (2014). Among other factors studied, economic wealth (GDP per capita) and the increased cost of autonomous vehicles to conventional vehicles were considered and subject to sensitivity analysis, which will allow the total model to be updated as new, more accurate statistics are determined. Their model showed that changes in the predicted market size have a very significant effect on the adoption rate, although not much on the time to market saturation.

A recent study by P. Bansal and K. Kockelman (2017) uses actual survey data, rather than assumptions based on previous new technology trends, to make penetration predictions for CATV technologies on its different levels. Survey respondents answered how much they are willing to pay for specific CATV technologies, gave some demographic information, and some information on how they use their vehicles. The model runs a number of dynamic simulations that assume 5% or 10% annual declines in the cost of CATV technologies, and then a number of other values assumed either dynamic or static. Customers willingness to pay for certain technologies will likely increase as the technology matures and becomes more widely understood, so simulations were run both with a static willingness to pay and with a 5% annual increase in willingness to pay. With a static willingness to pay, the study concludes that a 5% decrease in CATV prices will result in a 25% penetration for fully autonomous vehicles by 2045. On the optimistic side, a 10% increase in willingness to pay and 10% decrease in CATV costs would result in 87% penetration.

This dynamic prediction model presents a platform to assess potential economic goals of the CATV industry, which could serve as a tool in policymaking decisions to guide the growth of the industry. Many of the variables that are shown to increase market

penetration rates can be directly affected by government intervention: subsidies for the CATV industry would help to drop tech prices and meet peoples' price constraints, and further research could help reassure consumers of the benefits of the tech, likely increasing the amount they are willing to pay.

Workforce Disruption

In the United States, 2.86% of all workers are employed by driving occupations. The concept and implementation of autonomous vehicles has the likely outcome of putting these drivers out of work. By eliminating the human element in freight transportation, bus driving, and taxi driving, it would also stand to reason that fatigue, error, and overtime pay would also be eliminated. Autonomous vehicles for these kinds of occupations would be heavily incentivized for transportations company owners, and their high cost would likely be offset relatively quickly by the huge increases in efficiency.

It is estimated that four million driving occupation jobs would be lost in a rapid transition to autonomous vehicles. This would affect white men the most, as they constitute more than 2.1 million of the jobs that would be lost (52.5%). Nearly 16% of all driving occupation workers are unionized labor, and this organization is likely stand in strong opposition to any kind of supportive autonomous vehicle legislation.

There is little research done on how to address these workforce issues as CATV are developed. However, initial suggestions include unemployment insurance for these job sectors, education and retraining, and expanded Medicaid eligibility for these workers as they redevelop their skills and find new jobs (Solutions, 2017).

The workforce disruption that autonomous vehicles will cause poses a very high risk to the public and social adaption of autonomous vehicles. Special interest groups are likely to heavily oppose and influence legislation unless a viable option is made available to the four million people that would likely lose their jobs to these

vehicles. Despite all of the positive societal gains that would come from CATV, the society perceptions that their purchase or participation in autonomous vehicle transportation directly leads to four million people losing their jobs could be an enormous barrier to market entry.

As laid out by David (2015), the automation of jobs has been a periodic concern of workers for the last two centuries. Those concerned about unemployment as a result of automation are unsettled over the unpredictability of the future. New and ever-improving computing power, robotics, and artificial intelligence can replace labor to a heretofore unimagined scale.

However, "tasks that cannot be substituted by automation are generally complemented by it," which underlines previous cases in which workers have benefited from increased automation. Certain factors affect the impact on workers, especially how well certain skills and job tasks mesh with automation.

Naughton (2012) takes a strong position when he states that autonomous vehicles could soon make "many human skills worthless." Following the recession, job-creation remained lower and many economists indicated new technology research, such as the Google Car, as one major issue. Ultimately, the skill of driving may be increasingly devalued. This may have a negative effect on multiple industries.

In the United States, truck drivers - people employed in the truck transportation industry as drivers, truck drivers, or self-employed - account for about 1.7% of the employed population (Veryard & Daniel, 2017). Heavy truck driving as an occupation made up primarily of men between the ages of 40 and 60, with very few women or younger men. This part of the driving workforce is also aging faster than the rest of the workforce, with the average US truck driver in 2015 being 4 years older than the average worker.

Estimates of future supply of truck driver labor puts the US at an increase of 2.4 to 2.8 million in 2040. Further estimates measure the effect of the adoption of driverless truck technology on applicants, with faster adoption policies connected to a greater percent of applicants being dissuaded.

One conclusion from the projections is that there will be a large amount of road freight jobs lost with the adoption of driverless technologies. Alternative conclusions suggest that if driverless technology adoption occurs more slowly that displacement could be mitigated neatly. Ultimately, projections indicate that there could be negative effects from both quick adoption of autonomous technology and slow reaction by workers to the changing dynamic of the future job market.

Despite the loss of traditional road freight jobs, new jobs may be relevant for displaced drivers. Three possibilities are foreseen: remaining and new jobs in the trucking sector, remaining jobs in other sectors, and new jobs in other sectors. Depending on the tasks associated with a given job, there may be little motivation to automate certain jobs in the trucking sector. Urban jobs are less compatible with automation as compared to long-distance freight occupations and are less threatened by autonomous vehicles. Outside of the trucking sector, many jobs requiring novel human intellect and skilled trades are believed to resist automation.

The estimated loss of four million driving jobs as a result of a transition to autonomous vehicles does not include people employed in transportation companies, such as Uber and Lyft (Kalra, 2017). Whether these and the four million "traditional" driving occupations would be made obsolete may come down to the level of skill involved in the job. Based on the extent that driving is the essential part of different jobs (and able to be made fully automated), automation is estimated to threaten one-half to three-quarters of driving jobs.

White Americans make up 62% of the estimated four million driving jobs in the U.S., but people of color benefit by earning higher median annual wages (Ramachandran

& Vignesh., 2017). This median annual wage is nearly $2,500 higher than a non-driving job for African-American professional drivers, $2,000 for Native American drivers, and $5,800 for Latinos. Less jobs in the professional driving sector could therefore negatively impact the livelihoods of people of color in the United States.

Kalra (2017) indicates that the impact of automation in the professional driving sector can be dispersed through increased training. Drivers could also find opportunities to participate in higher-skilled labor for greater gain. A 2016 U.S. Government indicates four categories where jobs may experience growth rather than reduction: engagement, development, supervision, and response to paradigm shifts (*Artificial Intelligence, Automation, and the Economy. Executive Office of the President.* , 2016). Engagement, for example, a job in which a worker would deliver shipped goods the last 100 feet. Supervision jobs may include registration, testing, repair and maintenance, as well as supervision of vehicles in use. Self-driving car technology has the potential to increase the demand in urban planners to help with a changing built environment.

However, workforce disruption may also occur outside of professional driving occupations (Kalra, 2017). Autonomous vehicles are expected to be safer than traditional vehicles due to the elimination of human error. The result would be a decreased demand for labor in auto insurance, auto repair and body shops, health care, and legal services, all of which are involved in the industry of vehicular accidents.

A potential positive impact of autonomous vehicles on the workforce is an increase in access to jobs (Kalra 2017). Millions of Americans do not have access to reliable transportation, especially older adults, individuals with disabilities, and adolescents. Many Americans cannot afford to drive, with around 24 percent of households below the poverty line not owning a vehicle. The costs of projected shared autonomous vehicle services are estimated to be equivalent to public

transportation, to increase mobility in rural areas, and to be easily modified for accessibility needs.

Labor unions have called for lawmakers to slow down the process of changing regulations on autonomous vehicles (Beene & Widelson, 2017).. The president of the AFL-CIO's Transportation Trades Division indicated the opinion that more needs to be done "to understand the full effects." The general president of the International Brotherhood of Teamsters encouraged the inclusion of drivers at risk of losing their jobs in the discussions around autonomous vehicle regulations.

The trucking industry in the United States operates in a large and quickly growing market (Rossman & Jacob, 2017). 10.5 billion tons of freight per year (70% of the U.S. total) is transported in some way by via trucking. Trucking freight generates around $750 billion per year, and this comes with more motivation to innovate to capitalize on the market.

Truck driving is a large occupation in the U.S., as well as a popular one. In 29 out of 50 states it is the most popular occupation. However, with the projected growth of the industry, there is and will continue to be a shortage in drivers. Recruitment and retention programs in trucking companies have largely been unsuccessful due to perceptions of the industry as outdated and the restrictions placed on new applicants. Rossman (2017) indicates that this shortage is driving up labor rates, which now account for a third of the costs of transport. Autonomous vehicles may be one solution to removing these costs.

Nonetheless, certain job qualifications and tasks associated with truck driving may place limits on the extent that autonomous technology can be utilized. Tasks outside of driving include taking inventory, manipulating loading docks, inspecting loads, and placing orders. Citing the Brookings Insitute, Rossman points out that truck driving has a middle rank as to risk for automation. As stated by other authors, a truck driver of the future may have a reimagined and expanded role.

System Failure / Human Takeover

Throughout the varying levels of automation, the most critical safety question that is likely to arise is what will happen in the event of automation failure. When the automation fails, as it is almost guaranteed to do, will it fail suddenly or gracefully, and when it does fail, regardless of degradation speed, who will take over and how will they regain control safely?

Automated aids and decision support tools have been shown to increase human performance in a variety of fields, such as air traffic control, and have shown positive results in vehicle transportation as well. However, as systems become more automated, and the human becomes more passive, safety issues arise in the event of failure. Two of the most critical issues are situation awareness and skill degradation. Situation awareness is how conscious the human is of the system's current state, operations and surroundings. Skill degradation is the human's inability to safely and accurately perform routine, skilled tasks because those tasks are now routinely performed by the automated system (Hancock & Parasuraman, 1993).

Situation awareness is a genuine concern in highly automated systems where the human is relegated to the function of system monitor. It has been shown and is highly accepted that humans are notoriously poor at automation monitoring and their ability to step in and take over full functionality shortly after an automation failure is very low (Landry, 2014; Parasuraman & Riley, 1997; Prevot, Homola, & Mercer, 2008; Surakitbanharn, 2014). This is particularly an issue if the automation fails quickly, where the human would be required to take over full control of the system within 30 seconds or less. In such a case, it is extremely unlikely that the human operator could obtain even a basic level of situation awareness and take control of the system safely. If system degradation is graceful, that is, it fails in increments (or in a step-wise fashion) in such a way that the human takes over

functionally one step at a time, there is more opportunity for the operator to obtain situation awareness for a safe takeover (Merat, Jamson, Lai, Daly, & Carsten, 2014; Metzger & Parasuraman, 2005) .

There is very limited research and very limited understanding on how humans interact with automation at level 3 or beyond. Some initial work has been done to identify situation awareness for humans when interacting with level 3 automation, and it was found that attention to the centerline of the road decreases compared to level 0-2 automation. Drivers were also more keen and prone to divert their attention to other activities, such as watching a DVD or video on their phones. These secondary tasks were actually not found to be additionally detrimental to attention or ability to takeover (compared to just the level 3 automation and no secondary activity) for straightforward driving with no complexity (i.e. driving in a straight lane highway with no turns). However, when the task was more complex (higher traffic density, performing a lane change), the human operator's attention and ability to take-over from the automation and execute was drastically reduced (Carsten, Lai, Barnard, Jamson, & Merat, 2012). A similar experiment was designed to determine the performance of drivers when manual control was handed back when inattention was detected (extended period of time without eye engagement on the center liner) or after short-term, predetermined time periods (every six minutes, for example). The study found that human performance in driving was lower when the CATV initiated takeover when inattention was detected than on predetermined time intervals. However, it should be noted that there is an element of human learning to the time intervals method, where the driver becomes aware that their attention will be demanded in "X" amount of minutes, and when that time approaches, they are more likely to re-engage their situational attention. This work did not investigate mixed time intervals, or unexpected time intervals (Merat et al., 2014).

The current state of the art in autonomous vehicles has not progressed to a level that can guarantee a 100% crash free environment. It also has not progressed to a

level where system failure is impossible. Because of these two currently states of the technology, the human driver will need to be available for takeover in the event of a failure. However, as the level of automation increases, the ability of the human to do so decreases. This issue, from both social and ethical perspectives, will continue to plague CATV with its weight.

Safety

One of the most enticing elements of CATV and an automated vehicle environment is the possibility of reduced accidents, and by proxy, reduced loss of life in the transportation sector. In 2008, the Department of Transportation's National Highway Traffic Safety Administration published a report to evaluate the cause of accidents in the US. Of the 3,943,244 accidents evaluated, it was determined that 51.78% of those accidents were caused by human error (i.e. decision error, performance error, etc.) (Advisory, 2008). If autonomous vehicles were able to remove human error from the transportation system, it can be reasoned that the number of accidents, injuries and lives lost would also be reduced. It has been reasoned that even when the main cause of the accident is not deemed to be human error, the secondary cause or even co-cause of the accident is human error and that it may be upwards of 90% of all accidents are caused by human error (Fagnant & Kockelman, 2015).

Furthermore, in 2015, 10,265 people were killed as a result of drunk-driving accidents (Prevention, 2016). If autonomous vehicles were in place, and the driver were not expected to take over in the event of failure, it can be reasoned that drunk driving deaths and accidents would tend towards zero. These reductions in risk are large incentives for CATV and autonomous environments.

Another safety consideration that CATV brings is the ability to increase human mobility, particularly for those who currently cannot drive or drive poorly. If the

person were ill or otherwise impaired and therefore unable to drive a normal car, an autonomous vehicle may offer a solution for transportation without any added public risk (Greenblatt & Shaheen, 2015).

(Fagnant & Kockelman, 2015) reasons that CATV would not "fall prey" to the failing of human drivers such as drunk driving, distraction, drug involvement and fatigue. Removing these crash-causing elements could reduce up to 40% of crashes. However, as is outlined by (Campbell et al., 2010), designing a system that can perform safely in nearly every situation is challenging. For example, it is challenging for cameras to capture an obstacle in the road path and even more challenging for it to process and understand what that obstacle is, what kind of danger it poses, and then to develop a solution and execute it safely before hitting the obstacle. For the human operator, while driving, it is easy to recognize a human being, whether they are standing, sitting, walking, running, facing away or towards the driver, or any other permutation of being that a human can exist in. However, for a camera and computer processing system to recognize that the obstacle is a human, no matter it's form, shape, or activity, it can be very challenging. It is possible for poor weather to obscure real threats, or for unassuming objects like a cardboard box to be identified as a threatening obstacle (Farhadi, Endres, Hoiem, & Forsyth, 2009). These visualization issues are safety challenges that have yet to be addressed.

Despite issues that may impede market entrance due to safety, (Hayes, 2011) suggests that in a fully automated environment, it may be possible to reduce accidents to 1% of their current rate (~<40,000 accidents/year).

Another issue that can impact safety in an automated environment is the fact that the computer algorithms that control the CATV can only react, they cannot anticipate risk. Essentially, the CATV behaves in a "sense, plan, act" way, rather than an "anticipate, plan, mitigate" fashion (Bagloee, Tavana, Asadi, & Oliver, 2016). One of the main criticisms of this type of automation programming is that it is not always possible to know if there will be enough time to "sense, plan, and act" to avoid an

accident (Landry, 2012). Similar to the human experience of regaining situational awareness, where it could take a human up to 40 seconds to even realize a problem exists (Bonnefon, Shariff, & Rahwan, 2015) , because the computer can only determine a solution and enact it once it has sensed a problem, the amount of time available to do that may not be sufficient.

In other industries, such as air traffic control, potential solutions exist because the flight paths of aircraft are known (flight plans are filed with the FAA and programmed into connected GPS, while ADS-B in/out broadcasts and receives these plans to other aircraft), and while errors are possible, they exist in a bounded space due to the physical limitations of the aircraft itself. The known intent of the aircraft, paired with the known limitation of error, allows for pre-emptive or forward facing risk identification (Surakitbanharn, 2017). However, in CATV, the intent of other vehicles, as well as pedestrians, is not known. It is possible for travel path and destination of other CATV to be broadcast and known, like air traffic, and it is possible to predict with some level of accuracy the type of error possible by the machine itself. It is not possible to know or predict the intent of pedestrians. Because of this unknown, predicting possible accidents and practicing mitigation would be extremely challenging and would lack accuracy.

Algorithm & Programming Ethics

Most vehicles that employ any kind of automation use rule-based computer programming and algorithms to perform the tasks it is asked to execute. For example, the self-park function on some models of Mercedes Benz use rule-based programming; the camera on the back uses an algorithm to detect how far it is from the car behind it, and when it reaches a certain distance, the vehicle stops, and uses the front camera to judge the distance from the car in front, as well as from the curb. The cameras feed information to the computer, who computes distance, angle, speed, etc. and all this information is then fed into the parking algorithm, which,

based on these fixed measurements, makes decisions on how to maneuver the vehicle.

Rule-based programming will undoubtedly be the driving force behind CATV of the future, particularly as we move past level 3 automation. However efficient this process is, one of the most challenging questions in the CATV discussion is the ethics of this programming.

(Lin, 2016) lays out a scenario where a CATV is traveling at a certain speed, but is suddenly confronted with two obstacles, and no matter what maneuver is performed, the car will either hit one of those obstacles, or will stop in such a way that it would injure any passengers inside the vehicle. One obstacle is an 80-year-old woman and the other is an eight-year-old girl. No matter what happens, someone will be very severely injured or killed.   How does the computer make the decision on whom to injure or possibly kill?

Because the system is rule-based, it will make the same decision every time it is presented with this scenario. It may be programmed to always hit the person on the left-hand side, or the person closest to the vehicle, or it may be programmed to sacrifice the passenger. It may be programmed to hit someone that appears older, or that appears larger. No matter how it is programmed, the passenger (and owner) of the CATV will not have any say in how risk is managed; it is predetermined by the CATV manufacturer and ultimately, the person who programmed the rule-based software of that vehicle.

Ethically, some may argue that it is better to kill the 80-year-old woman and save the eight-year-old girl (she has more life to live), and yet again others may argue it is better to sacrifice the safety of the passenger, as they're the ones that have taken the risk by owning and/or riding in a CATV.   While neither of these options is necessarily correct, it highlights that different people would make different choices

in this dangerous scenario. This presents a moral challenge in the rule-based programming.

Consumers may find many advantages to a CATV, but one thing they will forfeit entirely is the option to choose the outcome.   In an autonomous driving environment, no matter how the passenger feels, the vehicle will always its rule-based programming, and will always hit the eight-year-old girl because she's on the left side (were it programmed to do so). The passenger, however, may feel as if "I would not have done that if I were driving," but there is nothing they can do to change the outcome. They also may be hesitant to get into a vehicle knowing it is programmed to sacrifice them or harm them before harming outside objects or people.   This inability to take responsibility for the actions vehicle based on personal morals and ethics may present a moral conundrum for the consumer.

Some suggest that in such scenarios, control could be handed back over to the driver so that he or she can make their own decision. However, as outlined in previous sections, it is unlikely that the driver would be able to regain control in a safe amount of time to execute a maneuver of any kind (Hancock & Parasuraman, 1993; Lin, 2016; Merat et al., 2014; Parasuraman & Riley, 1997; Prevot et al., 2008). This is unlikely to be a viable option.

Another possible way to avoid this ethical concern would be a perfect system where CATV would never crash into each other or into other objects in the environment. Of course, no CATV would ever be programmed to crash, but it is not likely it would be totally avoidable, despite the good intention in design. (Goodall, 2014) lists four reasons why an on-board computer might cause a crash; hardware failure, software bugs, perceptual errors and reasoning errors. A hardware failure might be a wire becomes loose, a software bug would be a break in coding (extremely common in computer programming), a perceptual error might be to misclassify an object on the road (the system may think it's stationary but it is actually a moving human), and a reasoning error might be that the system cannot accurately predict what that

human is going to do, or what his or her intent is at the time. This may cause this system to make a judgment error. Hardware failures can be mitigated with maintenance and with some relative predictability (time to failure for most parts of most engineered systems is known), but software failures happen rapidly and without warning, which could be risky, especially if the vehicle were traveling at high speeds. Perception and reasoning errors could be extremely dangerous, and cannot be predicted with reasonable accuracy, as it would be impossible to test the system in all scenarios that it could ever encounter.

The concept of perception and reasoning errors also makes this kind of programming very challenging for mixed-automation environments, where some cars would be fully automated, some with lower levels of automation and then perhaps some with no automation. It is challenging for algorithms to perceive what people will do, what their intent is, and how they will respond to situations. Therefore, the programming will appear rigid in contrast to human fluidity (Goodall, 2014).

Further ethical issues arise in programming the performance of CATV. Humans currently drive vehicles on the roadways today, and seemingly accept the current level of risk, accidents, and death. In order to solve some of the perfect automation issues, it has been suggested that CATV would only need to be programmed to meet the current standards of safety, and there would be no need to attempt to achieve a near-perfect system (Goodall, 2014; Lin, 2016). This suggest though that people would be willing to get into a CATV knowing the probability risk for accident, but having no way to control for it (i.e. drive more safely, slow down, take back roads, etc.). However, this may not be feasible, as millions of people fly on commercial airlines every day and accept a similar risk. However, the crucial difference may be that with flying, there is still a human pilot making the final decision (despite high levels of automation in the cockpit), but in a CATV, the computer automation would be making decisions with little to no input from the human user. Additionally, because it is impossible to predict the appearance of and intent of pedestrians, it is

not possible to fully quantify the safety level of the system, and it would not be possible to guarantee the level of safety that currently exists (or better).

(Bonnefon et al., 2015) suggest a series of ethical experiments where the moral algorithms that people are willing to accept could be identified. Online surveys were conducted where participants were given background stories of a traffic scenario, where their vehicle could either swerve into a barrier and the passenger (participant) die, or they could hit a pedestrian. The number of pedestrians that were saved varied (some participants would only save one, others 10, and all numbers in-between), the body making the decision varied (either the passenger or the computer system) and some participants were told to imagine themselves in the vehicle while others were told to imagine a 3rd party in the vehicle. In a second study, participants could tell the computer system to stay on course, swerve, or choose randomly. At the end of the experiment, participants were asked which choice they felt was more moral (to swerve or stay on course) and then finally were asked if it was morally appropriate to protect the driver or to maximize the amount of lives saved.

Most participants felt it was the moral choice to swerve and avoid the pedestrians, even at the cost of their own life or the life of the driver. When they were asked to imagine that they personally were driving and would die, the percentage of participants who chose to swerve decreased slightly. If the vehicle would kill just one person, around 60% of participants said they would swerve and risk their own life. However, if it jumped to killing 10 people, over 45% of participants said they would swerve to save those pedestrians, despite the risk to their own life. About 25% of participants did not feel comfortable making this moral choice, their life vs. others, and indicated they would let the computer choose which person to save at random (Bonnefon et al., 2015).

These experiments suggest that it is possible that people may understand the inherent moral dilemma of autonomous vehicles, but they also may be comfortable

or willing to give up the decision-making process to avoid culpability in the other person's death. However, this still does not suggest that humans would be comfortable letting a computer make a random decision on the fate of a human life.

Environmental Impact

CATV can make positive impacts by way of higher environmental standards than current motor vehicles. A conventional gas-powered CATV would likely to reduce fuel consumption compared to its human-driver counterpart by reducing suddenly accelerations, increasing smoother braking, making more efficient route choices with less traffic (and less engine idle time), and automatically optimizing cruise speed for fuel efficiency (Fagnant & Kockelman, 2015). It is estimated that fuel efficiency could be increased by 23-39% by utilizing these features in autonomous vehicles (Atiyeh, 2012).

It may also be possible for CATV to reduce traffic congestion. By utilizing the interconnected communication systems, autonomous vehicles would be able to better anticipate an appropriate travel speed to keep traffic flowing, and may be able to reduce sudden braking and accelerations in response to stop-and-go traffic. Additionally, cars may be able to follow each other more closely, as they would be able to communicate intent with each other and could warn vehicles behind them that they'd be braking and/or accelerating at some point in the future (Fagnant & Kockelman, 2015). Conversely, some research suggests that the miles traveled by autonomous vehicles would increase drastically compared to the miles traveled today by conventional cars. They would be no driver fatigue to combat, the market of those traveling would increase (those currently unable to drive or immobile would be free to travel), and they may be a shift away from public transport as it would no longer offer unique benefits, such as less time in traffic and the freedom to do other things will commuting (Greenblatt & Shaheen, 2015)

It is also possible for CATV to operate in an entirely electric space, requiring no fuel consumption whatsoever, or potentially as hybrids. This technology would decrease CO_2 emissions, decrease noise pollution and may help improve air quality as well as quality of life for people who live near roadways.

These environmental benefits are contingent upon large-scale market penetration (at least 90%), and are also subject to increases in overall demand of transportation. For example, if the 5.7 million passengers per day on New York City's subway system were to switch to autonomous vehicles, congestion on the city streets would drastically increase, and these kinds of benefits would not be realized. Additionally, it may encourage travelers to use CATV rather than fly, and while congestion may increase because of this switch, the positive environmental impact of less commercial flights would likely outweigh the negative impacts of increase road congestion. However, it is not yet known how user-participation in vehicle transportation would change (Greenblatt & Shaheen, 2015).

Shared autonomous vehicles (SAVs), or autonomous taxis, may be another solution towards lessening the impact cars have on the environment. Currently there are many car-sharing companies such as ZipCar and Car2Go that allow rentals in one location to be driven and dropped off in another location. There are also many cars, new and old that aren't being used. In fact, the US National Household Travel Survey (NHTS) data suggests that less than 17% of cars 10 years old or less are used at any given time. Autonomous vehicles as provided by car sharing companies or taxis, therefore, may be able to provide many environmental benefits, such as reduced parking and the need for vehicle ownership. Overall when compared to a typical American light duty vehicle, and SAV sedan could produce lower numbers in terms of energy usage, SO_2 released, CO released, NO_x, etc. This seems to indicate beneficial energy uses and lower amount of emissions, if the same distance was travelled by all the tested cars (Fagnant & Kockelman, 2014).

Fully-automated driverless vehicles will likely alter how both people and commercial goods are transported. They would be effective in reducing greenhouse emissions, at least the ones related to transportation. Transportation greenhouse emissions account for most of the total emissions around the world. However, certain legal mechanism must be put in place to encourage the use of automated vehicles. (Zushi, 2017). On the other hand, increase in AV usage may also increase the mobility of the elderly and disabled population. Though this would prove beneficial for societal reason, this may in fact increase the amount of greenhouse emissions rather than reduce them. It is also important to consider the fact that if AV use allows for people to leisurely use their travelling time, even usefully utilize it, as well as increase the notion of luxury travel, they would be less aggravated by the predicament of long travel. This could possibly mean a reduction in the number of travelers who choose to take a plane or a train, which also means there would be an increase in GHG per passenger-mile. It may also increase miles from under-served populations, especially in urban areas. (Heard & Miller, 2016).

Automobiles are a leading source of air pollution. The impervious surfaces that are necessary for today's normal mode of transportation also can impact both water quality in urban areas, as well as non-point source pollution from sediment from poorly managed construction sites. This also does not consider grease, oil, and other toxic chemicals from parking lots and roadways. Not only that, but communities may face water shortages as forests are replaced with road surfaces. This could mean that there would be a decrease in rainfall absorption into groundwater aquifers. Urban sprawl disrupts critical ecosystems and may end up further endangering imperiled species. Many believe that Avs would add to the addition of urban sprawl, as well as add to the adverse effects on the environment. However, Avs are expected to reduce both road lane width and need for parking in urban areas. Avs would either pilot themselves to a remote area after use, or they would drop off one passenger and pick up another if part of a taxi system (Harrington & Schenck, 2017). In Los Angeles for example, over 14% of all land is devoted to parking. The use of AV could lower the amount of land wasted on parking,

increasing the potential to use land for things such as parks, or additional green space. (Harrington & Schenck, 2017).

Non-freight transportation movements make up two thirds of the carbon emissions from the transportation sector. If new generation vehicle technologies are integrated, such as Cooperative Adaptive Cruise Control and Intelligent Traffic signals, the expected benefits of would delay reductions by up to 91% and up to 75% reductions in fuel use, as well as other measures. Combined, this can allow for communication of information between traffic signals and vehicles, such as communicating arrival times to adjust the signal timing at an intersection. Vehicle to infrastructure communication could hence reduce fuel consumption and CO2 emissions by reducing delays and stopping time (Malakorn and Park, 2010).

Although Avs have been gaining attention, Beiker and Meyer (2014) claim that widespread AV adoption could still be decades away, perhaps being too complex to adopt into society. If they are socially accepted, the transportation sector could become dominated by Avs in the future. Though many are hopeful that AV usage may reduce energy consumption, many still question it. The transportation sector can inherently impact energy consumptions in other sectors as well such as, commercial and residential building. One factor that could affect a vehicle's energy consumption is the vehicle's weight and performance. Characteristics of Avs, such as accident avoidance, could allow for lighter vehicles, reducing fuel consumption. Typical weight than would be placed in traditional safety precautions, such as around the driver's seat, could instead be eliminated or concentrated around the autonomous controls. Another factor affecting vehicle's energy consumption is the transportation network. A system of communication between vehicles could reduce the number of accidents and traffic situations. Platooning is an example of how communication by shortening traveling distances between vehicles could result in reduced drag. This reduced drag then translates to increases fuel efficiency. The factor with the greatest level of uncertainty however, is the consumer. The consumer ultimately decides the amount of energy efficiency through their

participation with autonomous technology. The consumers also affect AV usage by the services they demand. Consumers may increase energy consumption, if the services Avs could provide become widespread. For example, persons who are homebound, elderly, or disabled may start taking part in transportation services. Freeing passenger's attention from driving could also open time for other luxuries, likely subtracting from the normal sense of urgency or pressure to reach one place from another. This in turn may lead to more people being willing to utilize AV technology rather than take another mode of transportation. So while the first two factors point to an increase in fuel efficiency, the third points to a potential decrease. (Beiker & Meyer, 2014).

The negative consequences of urban transportation can also be prevented in many ways using autonomous vehicles and platooning. Platooning is a way to improve lane capacity, to play a part in contributing to overall faster and more energy efficient transportation, by eliminating the system of stopping and going that currently is widespread on roads. However, it is important to note that this would need to be performed on tracks that were specially evolved to possess dedicated tracks, and that which operate on a continuous basis from the start till the end. Intervehicle communication (IVC) is emerging as a means by which to decrease traffic. These include both short range (DSRC) and long-term (LTE-advanced) types of communication, along with cruise control and personal rapid transit (PRT) (Fernandes & Nunes, 2012).

Recently, the ARPA-E, or Advanced Research Projects Agency- Energy, started to give out grants to a handful of very large-scale projects, one of them being at Purdue University. The goal of the funding is to take whatever project that is being funded and get it to the market, within the span of three years, the main emphasis being placed on next generation connected and automated vehicles. The team at Purdue University needs to show a 20% fuel efficiency benefit in Class A trucks, a category that comprises of heavy duty vehicles, usually semi-trucks, that are over 80,000 pounds. The Department of energy requires that milestones are hit along the way.

The Purdue team has 3 different concepts that they are trying to address. The first is connectivity- being able to allow for remote calibration. Traditionally, when an engine is sold, that engine will always be a part of the truck it was sold to. However, now the goal is to be able to change calibration depending on where the truck is. For example, different calibrations are needed on different terrains to increase efficiency. The connectivity aspect of the project accounts for a 2.5% increase in fuel efficiency. The second aspect of the project is cloud-based optimization- using an off-board computation power to improve control and allow for real-time reactions to movements around a truck. This concept is expected to contribute 5% fuel efficiency. The final concept comprises of 3 parts: platooning, predictive cruise, and coordinated shifting to improve overall vehicle coordination. Peloton, a company dedicated to advancing Truck Platooning and Automation, is one the Purdue Team's partners on this project. Peloton currently has trucks on test tracks, and the company is studying connectivity between two or more trucks on a highway. Along with Peloton, other partners on this project include Cummins inc., a national renewable energy lab, as well as Peterbilt, a leading company in building tuck motors. Together, the collective goal is to enhance platooning and make is more widely accessible and approachable across the country.

Peloton has been working on technology that allows for surveillance of surrounding data such as data on weather condition, traffic, and construction. When a partner for platooning is available, the truck gets notified and the driver can make the decision to join the platoon or not. If the driver decides to join, then the cloud-based operating system will let the driver know what speed to proceed at to join the platoon. Once the platoon is created, the engine would maintain the same speed while the driver would just be tasked with steering the wheel. If a truck were driving alone on a highway, there would be drag from a vacuum effect that is created by the empty space behind the truck. If another truck were to join in a platoon, then that drag would be alleviated, allowing for a greater efficiency in fuel usage. By joining the platoon, the first truck would have a 10-12% efficiency in gas usage, while the following truck would have a 20% efficiency thanks to a reduction

in wind resistance. The platoon could be maintained at distances as close as 10ft apart. Inherently this implies that the autonomous system would be safer than using human judgment, with reaction time being a small fraction of that of a human. If a car were to cut in the middle of a platoon however, the system would sense the cut and adjust speeds accordingly to increase space between the vehicles. Likewise, if a vehicle were to leave in the middle, it would allow for a reformation of a platoon. The driver can also decide when he or she wants to end a platoon, and by pressing a button would be able to notify the other truck drivers of the upcoming departure. Platooning can increase fuel efficiency by reducing aerodynamic drag. The Purdue team is also considering ways in which the rest of the fuel cell can be used to save fuel, as well as into control strategies. Peloton is currently trying to sell platooning technology, hopefully at a cost of less than $3,000 per vehicle. The autonomous engines are compatible with any model of year of truck. The main concern here however is if the partners on this project would be able to convince people of buying this technology. How might people be motivated to spend money in order decrease the environmental impact that their truck would regularly have without the new autonomous system. Another hurdle in the implementation of this project may also be regulation restrictions, especially within different states. (A. Taylor, personal communication, September 29, 2017).

Increasing the number of autonomous vehicles would not only reduce pollutant emissions, it would also likely shift towards a mainly electric vehicle model, potentially leading to a drastic decrease in usage of gasoline and oil in automobiles (Bunghez, 2015).

Conclusion

Autonomous vehicle implementation would have an enormous impact on transportation in the United States and globally. There are many positive effects that would come from such a large-scale innovation, but there are many barriers that must be overcome to achieve successful execution and societal acceptance. Research is ongoing, especially focused on technology and programming development and capability, but a robust development of public policy to address social, legal and ethical issues must be integrated for measurable success of connected and autonomous vehicles.

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